A TEXT-BOOK

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BY

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WITH 165 ILLUSTRATIONS AND SELECTED TABLES OF TRIALS.

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NOTE TO THE FOURTH EDITION.

THIS Edition has been brought up to date by the late Mr. Bryan Donkin's Secretary, who desires to take this opportunity of gratefully acknowledging the invaluable assistance rendered by scientific friends, both in England and abroad. Special thanks are due to Professors Hudson Beare, Meyer, Capper, Hutton (of Columbia University), and Boulvin; to Messrs. Dugald Clerk, Bellamy, Cecil Cochrane, Diesel, the Secretary of the Institution of Mechanical Engineers, and others; and also to various English and foreign engineering firms, for valuable information courteously afforded.

The chief changes to note since the publication of the Third Edition are, firstly, the increase in size and efficiency of internal combustion engines. Motors driven with cheap power and blast-furnace gases are now built up to 2,000 to 4,000 H.P., and among the pioneers in this movement are the Cockerill firm at Seraing, in whose hands a French engine, the Simplex, has become one of the leading types. The utilisation of blast-furnace gases has been rapidly developed on the Continent. For the large powers now required, double-acting engines have come much to the front, and the great heat developed is carried off by an efficient system of water cooling. Special attention has been given to the internal working of gas and oil engines, and compression pressures ranging from 160 to 350 lbs. per square inch have been realized, with a corresponding increase in the heat efficiency. The regulation of the speed has been carefully studied, and large gas engines are now governed with as much precision as the best steam engines, the "hit-and-miss" principle being no longer applied to any but small motors. In oil engines it is still usual. The problems

connected with the utilisation of the heat supplied have been elucidated, to which the analysis of the exhaust gases, which forms a part of all good tests, has much contributed.

The Tables of Trials have been brought up to date, and several interesting additions will be found in them.

November, 1905.

PREFACE TO THE FIRST EDITION.

THE subject of Internal Combustion Motors, or engines for obtaining power without a boiler, is one of great and increasing importance, and it was, therefore, with pleasure that I undertook the following work at the request of the publishers.

It is divided into three parts, treating respectively of Gas, Air, and Oil Engines. Part I., Gas Engines, is divided into two sections, the first dealing with the early history of these motors, and the second with modern gas engines. In this latter part particularly I am much indebted to numerous recognised authorities on the subject, especially to the excellent works of Professors Schöttler and Witz, Mr. Dugald Clerk, Professors Jenkin and Robinson, M. Chauveau, and others. Information has also been obtained from the *Proceedings of the Institution of Civil Engineers*, *Proceedings of the Institution of Mechanical Engineers*, *Comptes Rendus de la Société des Ingénieurs Civils*, *Zeitschrift des Vereines deutscher Ingénieure*, *The Engineer*, *Engineering*, and various other scientific and technical periodicals. A list is given of the literature of the subject, both English and foreign, which, it is hoped, will be found fairly complete.

The Theory of the Gas Engine is briefly discussed, and here I have had the advantage of the remarks and valuable criticism of Professor Capper, of King's College, London, who also kindly made for publication in this work a new test upon the experimental Otto-Crossley gas engine in the Engineering Laboratory of King's College—a test which is, perhaps, as complete as any that have been published. The chapter on the "Chemical Composition of Gas"—an important part of the subject—has been entrusted to Mr. G. N. Huntly, A.R.C.S. of the State Medicine Laboratory, King's College, who is responsible for this chapter only.

Care has been taken to consult the best authorities in England and on the Continent who have written on the theory and practice of gas engines, and to bring the matter up to date. I have much

pleasure in acknowledging my special obligations under this head to M. Delamare-Deboutteville of Rouen, and Professor Schröter of Munich, for their kind assistance. To Professor Kennedy, F.R.S., also, who has made many exhaustive and reliable tests on English gas engines, my acknowledgments are due. Not much original work appears to have been done in the United States, but the subject has been thoroughly studied in France and Germany.

An Appendix is added, containing information which it was not found possible to incorporate in the text. One of them gives an abstract of the valuable experiments recently made by Dr. Slaby of Berlin, and published after the main portion of this work was complete.

In conclusion, there only remains for me to emphasize the fact of the constantly increasing use of these motors in all countries for industrial purposes. Undoubtedly, there is a great future before them. There still exists, however, a large field for economy. In both Oil and Gas Engines, about 40 per cent. of all the heat received now goes off in the exhaust gases, and about 35 per cent. in the jacket water. The better the economic results obtained, the greater will be the demand for these convenient motors. At present their chief recommendation is the absence of a boiler, which is of great advantage, especially for small powers. Even with the very high temperatures in the cylinders there is also little or no difficulty with lubrication. They are yearly increasing in size and power, and will certainly before long, as more knowledge and experience are brought to bear on their construction, enter into formidable competition with the best steam engines. They may even constitute the principal heat motors of the future.

A list has been added of the chief tests on Gas, Oil, and Air Engines that have been published up to date.

BRYAN DONKIN.

LONDON, *November*, *1893*.

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DEVELOPMENT OF THE MODERN *GAS* ENGINE.

APPROXIMATE DATES.

	Year
First horizontal Lenoir French engine, water jacketted, with slide valve (40 cubic feet of gas per I.H.P. hour). Electric ignition,	1861
Hugon gas engine. First with ignition slide valve,	1863
Otto & Langen's atmospheric engine,	1866
Practically very few English makers of gas engines, perhaps one or two,	1870
Bisschop engine, made by Andrews,	1872
Robson, compression on one side of piston, and ignition on the other,	1877
First Clerk engine with air pump and compression,	1877
First horizontal Otto engine, Crossley (25 cubic feet gas per I.H.P. hour),	1879
Robson, first starter of compressed gas in a reservoir,	1879
Firms making gas engines in England—Simon, Andrews, Tangye, Robson, and others,	1880
Dowson first gas producer,	1878-1880
Heat efficiency of the best engines, 10 to 15 per cent.,	1882
First porcelain tube ignition, Watson,	1881
Best heat efficiency of Otto engine (5 to 15 I.H.P.), 15 per cent. (taking indicated work),	1887
First Otto-Crossley without slide,	1888
Society of Arts' trials—Otto-Crossley engine, 22 per cent. heat efficiency (taking B.H.P.),	1888
First Daimler gas engine,	1889
First timing valve, Otto-Crossley engine over 100 B.H.P.,	1889
Expiration of Otto patent in England,	1890
Maximum power, 200 to 300 I.H.P. engines in England, France, and Germany,	1890-1894
Approximate number of firms making gas engines—England 30, Germany 30, France 20, Switzerland 5,	
Power gas, $\frac{3}{4}$ lb. to 1 lb., good anthracite coal per B.H.P., 50 to 200 H.P.,	
Heat efficiency, 16 per cent. to 25 per cent. in best engines (taking B.H.P.),	1895
Maximum initial pressure in cylinder about 200 lbs.,	
Largest engines made about 300 to 400 I.H.P.,	
First application of blast-furnace gases,	
Largest gas engine made, 1,500 I.H.P.,	
Heat efficiency of the best engines per B.H.P., 25 per cent. (23 B.H.P.),	1899
Number of firms making gas engines—about 50 in Great Britain,	
Mean pressure in latest engines about 110 lbs. per square inch,	
Largest gas engine made, 4,000 H.P.,	1905
Heat efficiency of the best engines per B.H.P., 29½ per cent. (65 B.H.P.),	

DEVELOPMENT OF THE MODERN *OIL* ENGINE.

APPROXIMATE DATES.

	Year
First oil engine exhibited at the Royal Agricultural Society's Show at Newcastle (Spiel's petroleum engine) by Shirlaw & Co., Nottingham, . .	1887
Messrs. Priestman first exhibited a 4 H.P. petroleum engine at the Nottingham Meeting of the Royal Agricultural Society, using ordinary lamp oil, ...	1888
One or two makers in England, ...	1888
A 6 H.P. portable oil engine exhibited at the Windsor Meeting of the Royal Agricultural Society by Messrs. Priestman, ...	1889
Royal Agricultural Society, Plymouth Meeting. Light portable motors. Prize awarded to Messrs. Priestman for 4½ H.P. portable, . .	1890
Royal Agricultural Society, Cambridge Meeting. Fixed engines, 4 to 8 B.H.P., 11 exhibited. Portable engines, 9 to 16 B.H.P., 6 exhibited. Prizes awarded to Messrs. Hornsby and Messrs. Crossley, . .	1894
Approximate number of firms making oil engines—Germany 30, England 20, France 10, Switzerland 5, ...	1895
Heat efficiency in the best engines, taking B.H.P. 10 per cent. to 20 per cent.,	1895
Largest engines made about 60 I.H.P., ...	1895
First Diesel oil engine about	1895
Number of firms making oil engines—about 30 in Great Britain, . .	1899
Heat efficiency of the best engines per B.H.P. about 27 per cent. for 25 B.H.P. engine, ...	1899
Largest engine made, 60 H.P., about	1899
Meaux tests—Professor Ringelmann, ...	1894
Berlin Tests—Professor Hartmann, ...	1894
Largest engines made, 200 H.P. and upwards, ...	1905
Heat efficiency of the best engines per B.H.P., 32 per cent., . . .	1905

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A TEXT-BOOK OF
GAS, OIL, AND AIR ENGINES.

PART I.—GAS ENGINES.

CHAPTER I.

GENERAL DESCRIPTION OF THE ACTION AND PARTS OF A GAS ENGINE.

CONTENTS.—Introduction—Advantages of a Gas Engine—Waste of Heat—Source of Power—Utilisation of Motive Force—Parts of a Gas Engine—Transmission of Energy—Admission of Gas and Air—Ignition—Explosion and Expansion—Exhaust—Compression—Oiling—Regulation of Speed.

THE principles governing the construction and action of a gas motor are almost the same as those of a steam engine. In both the object is to obtain useful work from heat. This is effected by raising water or gas to a certain temperature, producing in the one case steam, in the other flame, and, with the pressures resulting from the increase of heat in the steam or flame, driving forward a piston connected to a shaft. The science of thermo-dynamics proves that there exists a strict ratio between the heat evolved and the work performed. The laws governing the production of this heat energy are always the same, whatever the medium or agent of motive force.

In mechanical motors there are three points to be considered:—1st. The cause of motion, varying according to the type of motor. In thermal engines it is heat obtained from the combustion of coal in a boiler or air furnace, or by the explosion of inflammable gases. 2nd. The effect produced, or the energy into which the heat is transformed; this usually takes the form of pressure upon a piston working on to a crank. So far, all heat motors are alike. 3rd. The particular mechanism, differing in each kind of motor, by which this translation

of heat into work is utilised. The difference between steam and other kinds of motors, such as gas, air, petroleum, &c., lies in the means employed to generate the heat, and turn it into work.

A steam motor consists of three indispensable parts, the furnace, the boiler, and the cylinder containing the motor piston. These may be in close proximity to each other, but there is usually a separate building for the boiler, &c. The process of starting a steam engine is relatively slow and laborious. The fire must be kindled and combustion obtained in the furnace, and the water in the boiler brought to boiling point and evaporated into steam. The temperature must then be raised until the pressure of the steam, produced by the increase of temperature, is sufficient to propel the motor piston.

Advantages of a Gas Engine.—In a gas engine these operations are much simpler, because it is so constructed that, for the work it has to perform, it is complete in itself, containing on one foundation the equivalent of furnace, boiler, and cylinder. It is in the cylinder that the production and utilisation of the heat take place, and the entire cycle, or series of operations, is completely carried out. Highly inflammable gases and air are first admitted into the cylinder. They are, at a given moment, exploded by the application of heat or flame; the pressure and the temperature are at once considerably raised, and the piston is driven forward. In a steam engine the working agent is produced separately and continuously, but in a gas motor the explosive charge, which acts as the medium of heat, must be formed afresh at each stroke of the piston. With gas there is very little difficulty in obtaining an explosion, and a corresponding backward and forward stroke, as many times in a minute as is required. As combustion takes place in the cylinder itself, pressures and temperatures much greater than those developed in steam engines are easily and quickly produced. Gas motors are called "internal combustion" engines, and the same name is used for all motors in which the heat is generated inside, instead of outside, the cylinder.

This brief outline of the working of a gas motor shows the advantages it possesses in practice over the steam engine—namely, compactness and facility in starting. Theoretically, it is also superior, because higher initial temperatures are available, to act upon the piston. But in all heat motors hitherto made, there are defects which the skill of the best constructors has not yet been able to overcome—namely, waste of the greater part of the heat generated, and consequent loss of pressure, or of useful work done upon the piston.

Considering, first, the practical advantages of the gas engine, as far as compactness is concerned, it leaves little to be desired. The space it occupies is small, a few square feet being sufficient, instead of

the separate boiler and chimney necessary with a steam engine.* A gas motor can be fixed almost anywhere, but it should stand on a solid foundation, to counteract the vibrations caused by the repeated explosions. To place it in proper working condition, all that is required is a gas supply pipe and a water tank with pipes for cooling the cylinder. The high temperatures produced by the explosion of the gases necessitate the use of a jacket round the cylinder, through which water circulating automatically from a tank passes continuously, to keep it cool; this jacket water is used over and over again. These pipes, with a third communicating with the outer air, and providing an outlet for the burnt gases, constitute all the necessary working connections.

A gas engine thus easily fixed, can also be set in motion and started in a few minutes. If a gas jet or hot ignition tube is used to fire the charge, the gas is previously lighted; where combustion is obtained electrically, the generation of the sparks is produced before the engine is started. A few turns by hand or other means are given to the flywheel, while the exhaust is kept open, and the engine is then fairly at work. To stop it, nothing is needed but to turn off the supply of gas. For small manufactures the convenience of having a motive power at hand, easy to start or stop in a few moments, is so great, that small gas motors are rapidly superseding, not only steam, but manual labour. It cannot be denied that they are rather more costly than steam, but of late years their consumption of gas per H.P. has been much reduced. In proportion as the quantity of gas required to drive them is diminished, and the economy obtained is greater, the more popular and cheaper will they become. Practically, there is less danger of fire than with steam boilers, and thousands of gas engines are now used in places where steam could never be employed.

It is in the smaller gas engines that these practical advantages are chiefly felt, but the theoretical superiority of these motors, obtained by the high temperatures at which they can be worked, applies equally to engines of all sizes. But as soon as large powers are required, and the gas engine enters into active competition with steam, it becomes of far greater importance to economise the consumption of gas. The temperatures and pressures obtained by the inflammation and explosion of gas in a cylinder are so high, that engineers have not yet succeeded in utilising them to their full extent. Hence, there is much waste of heat and consequent loss of pressure, and these defects in the working of a gas engine affect injuriously the expenditure of gas. If heat be wasted, more must be supplied, and more gas must be used to produce it.

Waste of Heat.—In a steam engine the main object should be to

* This applies only to smaller motors, and not to gas engines of 1,000 H.P. and upwards, now constructed by several makers (1904).

keep the cylinder walls as hot as possible, to prevent the condensation of the steam. The difficulty of generating steam, and maintaining its temperature and pressure, is increased, because there is a change of physical state from a liquid to steam. With a gas engine the reverse process is necessary, and the cylinder walls must be cooled. The gas is dry, and the heat developed by the explosion taking place in the cylinder acts directly on the piston. A considerable amount of steam is condensed in the pipes of a steam engine, whereas in a gas motor there is no similar waste, because all the heat is generated in the cylinder itself. Nevertheless heat is lost, but in a different way. The temperature of the gas at the moment of explosion is relatively high. It is generally about 2,730° F. (1,500° C.); but this is not the highest temperature reached. Whatever the actual temperature, the heat is always too great to be retained; a large portion is sacrificed, to prevent injury and destruction to the parts, and heat is also carried off continuously by the cooling water round the cylinder. In the early double-acting engines, not more than 4 to 6 per cent. of the total heat received was employed in doing work, and more than half was wasted, that the walls might be kept cool. If to this be added the heat escaping from the cylinder in the exhaust gases, or the products of combustion, it is not difficult to understand how, formerly, from 94 to 96 per cent. of the heat was dissipated.

It is this waste of heat in a gas motor that causes the loss of pressure, or diminution in the work done on the piston. With all gases the pressure increases with the rise in temperature, and therefore the higher the temperature, the greater will be the pressure produced, or the expansion of the gases. If this pressure be expended in doing work, and acting on the piston, the whole may, if expansion be continued long enough, be utilised in useful work. But to obtain this result with the pressures generated in a gas engine, the cylinder and piston must be of a certain length, and the piston allowed to move out as long as there is any expansive force left in the gas, to act upon it. As this is practically impossible, the other plan is to diminish the quantity of gas admitted into the cylinder. Before compression was employed, it was not easy to proportion the supply of gas and air to the expansion, but now that high compression is always used in all modern engines, no difficulties in this respect are experienced.

When the theory of the gas engine began to be really understood, the principal problem was, how to obtain sufficient expansion from the exploded gases. The test of efficiency in any heat engine is the proportion between the total heat supplied and the total useful work obtained. As far as work is concerned, all the heat which is not employed in producing it is wasted. Thus to be really efficient, a gas engine ought to furnish a maximum amount of useful work with a minimum consumption

of gas. This is only possible if the expansion of the gases is rapid and prolonged. The greater the time allowed them to act upon the piston, and the further they drive it, the more heat energy will be expended in work, and the less will be discharged as waste into the atmosphere. Expansion should also be rapid, because the more quickly the piston uncovers successive portions of the cylinder walls, the less time there will be for useful heat to be carried off from the hot gases to the cooler walls. This important question of expansion will be more fully examined when considering the theory and utilisation of heat in a gas engine.

The study of a gas engine falls naturally into two divisions :—

I. The source of power, or motive force.
II. Its mechanical utilisation.

I. Source of Power.—In all heat engines the source of power is heat, and gas is the medium or agent through which it acts in a gas motor. The gas is ignited, and the explosive force thus generated is used to drive forward a piston. Many different kinds of gas, varying in heating value, are employed, and the effects obtained by ignition and explosion cannot be determined without a knowledge of the chemical constituents of the gas, and the proportions in which they combine with the oxygen of the air. Since the gas used in an engine cylinder does not contain the oxygen necessary for combustion, it can never be burnt by itself, but must always be diluted with a certain quantity of air. Unless the composition of the gas and the ratio of its dilution with air are known, it is impossible to ascertain the temperatures and pressures attained in the cylinder, and to calculate the theoretical work, or the work it ought to do. The study of gases has led to the discovery of the law of dissociation, or the property they possess, after they have attained a certain high temperature, of resolving into their separate elements. The phenomena of ignition in a cylinder also prove that the whole heat of the gases is never developed at once, whatever the gas used, or the proportions in which it is diluted with air. It appears probable that combustion is seldom complete and instantaneous, but continues during the forward motion of the piston, after the first propagation of heat which causes the explosion. These and other questions connected with the phenomena of combustion in a gas engine are only mentioned here, and will be discussed later.

II. Utilisation of the Explosive Force, &c.—In the second part of the subject we have to consider the mechanical utilisation of the motive force, or the method by which it is turned into rotatory motion. This includes a study of the construction and parts of a gas engine, as the apparatus used for the transformation of heat into useful power. There is this peculiarity in its structure, that the cylinder contains in

itself furnace and boiler, and in it the motive power is developed. Before examining in detail the various types, it will be well to explain the principal parts of a gas motor and its internal organisation. We will first enumerate these parts, and then describe the functions they have to perform, as also the different operations taking place in a gas engine.

Base.—The base plate on which the engine is fixed and the cylinder bolted is of cast iron, and usually very solid. In oil engines the interior of the base plate is often utilised as a reservoir for oil.

Cylinder.—The cylinder, firmly bolted to the base, is either vertical or horizontal, according to the type of motor. In the smaller sizes, gas engines have usually one motor cylinder, working single-acting; it is almost always open to the atmosphere at the crank end, and closed only by the piston. No second cylinder is needed to increase the motive power, sufficient force being obtained by the succession of explosions in one cylinder. For larger types two or more single- or double-acting cylinders are used. As the great object in a gas engine is to allow the gases to expand as completely as possible, it seems at first as though this end would be best attained by making the engines compound, like steam engines, and causing the gases to expand successively in different cylinders. Though often tried, this arrangement has not been found successful. Sometimes an auxiliary pump is used for compressing the mixture, or a charging cylinder for receiving and mixing the gas and air. Compression is nearly always obtained in the motor cylinder itself, and the motor piston acts on one side as a pump. A special feature of gas engine cylinders is that, on account of the great heat developed, they are always provided with some apparatus for cooling the walls. In the smallest types it has been found sufficient to make the outer radiating surfaces of the cylinder ribbed or deeply indented, exposing a large cooling area to the air. In engines developing above two or three horse-power, a jacket with water constantly circulating through it is indispensable. As one end of the cylinder is almost always open to the air, the cylinder metal is kept cooler, and over-heating is diminished by contact with the outer air, but chiefly by the water jacket.

Pistons.—The pistons of gas motors are very similar to those of steam engines, but much longer. They are generally plunger pistons, and three or four sets of Ramsbottom rings, well fitted, are now nearly always used.

Valves.—The valves of a gas engine perform functions different to, but not less important than, the admission and exhaust valves of a steam engine. Not only do they admit the gases into the cylinder and discharge the products of combustion, but they also assist a little in mixing the gas and air, and a special kind, known as a timing valve, causes ignition at the proper time. In the older types of engine, as in

the early Otto, there was generally one slide valve for admitting and igniting the charge. It contained ports to receive and pass on the gas and air to the cylinder, and carried a lighted flame within a cavity to kindle the charge, after it was mixed and compressed. In most modern engines lift valves alone are used, but occasionally the mixture is admitted to the cylinder through cylindrical or piston valves. In most engines the valves are worked by cams on a side shaft driven from the main shaft, or by eccentrics; in others they are automatically lifted or closed by the pressures in the cylinder.

Transmission of Energy.—As in a steam engine, the pressure of explosion is generally transmitted direct to the revolving crank shaft. Usually there is no connecting-rod, especially in smaller engines, the piston-rod working direct on to the crank. To obtain greater regularity in the action of the engine, the flywheel is usually made larger and heavier than in steam engines. Most gas engines have only one explosion per two revolutions, and the energy of the flywheel is required to carry the piston forward, take in a fresh charge of gas and air, and to bring it back to the dead point after explosion.

In all gas engines five operations are required for a complete cycle :—I. Admission and mixture of the charge of gas and air. II. Ignition. III. Explosion. IV. Expansion. V. Exhaust, or the discharge of the gases and products of combustion. To these another has been added in modern engines—namely, Compression.* This cycle of work corresponds to each explosion, but not necessarily to each revolution; indeed, in many engines the number of revolutions and of explosions are independent of each other. The nature of these operations is as follows :—

I. Admission of the Gas and Air to the Cylinder.—This was formerly supposed to be a complicated process, and great care was taken to provide separate valves for admitting the air, and conducting the charge to the cylinder. Experience has shown that the air enters freely through any aperture, which is usually placed in proximity to the gas admission valve. Gas, unless made specially on the spot, is admitted through a pipe from any ordinary gas main. In the older engines, admission of the charge was made through a slide valve, as already described, moving to and fro between the slide cover and the cylinder. The gas pipe communicated with a passage in the slide cover, and a hole in the slide valve leading to a cavity. As soon as the cavity was filled with gas, the movement of the slide brought it opposite a similar opening in the cylinder, through which the gas entered. In later engines admission is effected through ordinary lift valves. Before entering the cylinder, the gas usually passes through a chamber where it is thoroughly

* In some engines part of a stroke is devoted to cleansing the cylinder of the burnt products.

mixed with its proper proportion of air, admitted through a separate inlet. Much importance was attached to this process of mixing before the use of compression, and different methods were resorted to, either to mix the gas and air, or to keep them in separate layers, and stratify them as they entered the cylinder. It is now almost universally admitted that these arrangements do not influence the explosion, and that stratification does not take place in the manner supposed, owing to the compressive force exerted by the piston. The gas admission valve is usually connected to the governor, which regulates the quantity of gas entering, and consequently the number or strength of the explosions.

II. Ignition.—The gases being admitted into the cylinder, the next operation is to fire or ignite them. In the early days of gas engine construction with flame ignition, this was a delicate process, because the return stroke of the piston exerted a considerable pressure upon the charge, and sometimes blew out the flame. The difficulty was increased by the previous compression of the gas and air. Two methods of ignition are now employed—1. The electric spark. 2. A tube maintained at a red heat by a gas burner. Electricity was the first means proposed and adopted for igniting the gases, and it is largely used in foreign engines. A current of electricity passes along wires placed close to the valve or chamber admitting the charge of gas and air, sparks are continually formed and fire the mixture. Magneto-electric ignition is also usual, especially if the engine is driven by producer or blast-furnace gases; the spark is generated by a contact-breaker worked from the cam shaft. With flame ignition the charge, after being admitted into the slide valve and mixed, was, in compression engines, carried past a flame burning in a hollow of the valve. When the mixture was ignited the pressure of the burning gas often put out the flame, and it was then relighted by an external permanent burner. The slide valve was held by springs against the cylinder, and worked by an eccentric, but more often by a cam on the auxiliary or counter shaft driven from the main shaft. Ignition by a flame is now obsolete, and in England the most general method is by a hot tube. At a given moment the opening to this tube is uncovered, a portion of the charge at high pressure is brought in contact with it and fired, and explodes the remainder in the cylinder. The tube is kept at a red heat by a gas burner, and is easily replaced from time to time when worn out. Formerly these tubes were made of iron, and were "short-lived," as it is termed; very small tubes of platinum and other metals are sometimes used, which last much longer.* In some of the older types of engines, where the charge was admitted at atmospheric pressure, the gas and air were drawn in at one end of the cylinder by the

* Porcelain tubes are also much employed, but are scarcely suitable for oil engines, as they are apt to crack.

suction of the forward stroke of the piston. At a certain moment a small flap valve covering a flame burning on the outside of the cylinder was lifted by the pressure, the flame drawn forward, and the mixture thus ignited. Sometimes the piston itself, in its out stroke, is used to uncover the gas and air valves. In other engines the gases are ignited in a separate chamber; there is no explosion, but they enter the cylinder in a state of flame, and force the piston forward.

III. and IV. Explosion and Expansion.—It is in the motor cylinder that explosion and expansion of the ignited gases always take place. To allow room for the compression and ignition of the charge, the clearance space is usually much larger than in steam engines, sometimes so large that it forms a separate chamber, into which the gas mixture is compressed.* In the earlier types of gas motors, the charge was drawn in during the first part of the forward stroke, explosion taking place only when the piston had almost reached the middle of the cylinder. It was soon found that this tardy explosion greatly limited the number of expansions, and the work performed by the gases on the piston. Modern engines are designed to procure the explosion as near the beginning of the stroke as possible, so as to allow the maximum volume of the cylinder for the expansion of the gases. In some vertical non-compression engines the clearance space was exceedingly small. Explosion of the gases took place when the piston was at the bottom of its stroke, free of the crank and shaft, and drove it to the top of the cylinder.

V. Exhaust, or discharge of the gases.—Various methods are employed in gas engines for getting rid of the products of combustion, but the best authorities are now agreed that they should be expelled from the cylinder as quickly and as completely as possible. Most modern gas motors being single-acting, or acting on one side of the piston only, the exhaust valve is seldom opened during the forward stroke. In some engines it only opens during half the return stroke, in others the whole of this stroke is utilised to expel the previous charge, while in a few engines a complete stroke, forward and return, is sacrificed to discharge the products of combustion, and cleanse the cylinder. Air under pressure is admitted to help the discharge in some modern engines. The exhaust valve plays an important part in a gas engine, because the high pressure in the cylinder is, of course, instantly reduced as soon as it is opened. Most gas engines are so constructed that the unburnt gases are allowed to escape at a relatively high pressure and temperature, which are thus wasted, instead of being utilised. This is one of the defects of these motors which engineers should be most anxious to remedy. In some of the older vertical engines the piston was forced up by the

* The tendency in modern engines is greatly to reduce the compression space, and thus to increase compression.

explosion and driven down by atmospheric pressure, a partial vacuum being formed below by the cooling of the gases. The opening of the exhaust valve at the bottom of the cylinder, by causing the air to enter, equalised the pressure above and below the piston, and checked its descent. In these earlier motors the exhaust was usually connected to the admission and ignition valves, and one slide valve was made, during its motion to and fro, to uncover the three different openings. In others, and generally in the modern horizontal engines, the exhaust is under the cylinder, distinct from the admission valves, but worked from the same side shaft.

Compression of the charge.—To compress the gas and air before ignition in an engine cylinder is necessary for economy. This is the most important modern improvement introduced into the cycle. As compared with the other operations, compression has certainly the greatest influence on the lower consumption of gas, and the economical working of the engine. It is effected in the following way:—A certain quantity of gas and air, in definite proportions, is admitted into the cylinder. Instead of being immediately ignited the mixture is compressed, and its pressure raised—that is, the volume of gas and air is forced into a much smaller space than before, by the return stroke of the motor piston. If, for example, the charge occupied a space of 5 cubic feet, it is driven back by the piston till it occupies only, say, 1 cubic foot, or one-fifth the previous space, and the pressure is raised five fold. The method usually adopted is to allow the piston to move out, and take in gas and air behind it till the whole cylinder is filled; the piston then returns, all the valves and ports being closed, and the mixture is driven into the clearance space and compressed. The advantages of this process are, that the particles of gas and air are forced much more closely together, and when they are ignited, their power of expansion has been found by experiment to be much greater. Nor do they part with their heat so quickly, being confined in a smaller space. Writers on the gas engine are unanimously of opinion that compression, previous to ignition, is the one great source of economy in gas motors, and this is confirmed by experiments. In the older non-compressing gas engines, it was always difficult to raise the pressure of the gases high enough to obtain much work on the piston. In modern compression engines, on the contrary, the expansive force of the gases is greater than can be properly utilised.

The advantages of compression are—(1) *The smaller size of cylinder required.* In the early engines, to obtain an effective working pressure, the cylinders were made large, and as much gas and air as possible admitted at a time, and even then the pressure was often very low. But with engines using compression, since the same charge occupies a smaller space, the cylinder can be made smaller. (2) *Greater certainty*

and rapidity of explosion, because the particles of gas, being forced closer together, and their temperature raised by compression, ignition proceeds more rapidly, and a more vigorous explosion is obtained. The flame is easily and surely transmitted, permeates the whole mass almost instantaneously, and the entire force of the explosion is developed. (3) *Greater economy of gas*, because, inflammation being certain, a poorer quality of gas can be used. Not only may the quantity be smaller in proportion to air, but the weaker charge, if compressed, will still explode, even when further diluted with the products of former combustion. (4) *A smaller cylinder is required for the same power* (see Chapters xv. and xvi., where this subject is fully treated).

Compression is carried out in two ways. As a rule, the engine has a single motor cylinder, in which it takes place, two strokes, forward and return, being generally sacrificed to obtain it. If a pump is added, the charge is compressed by it; every stroke of the motor piston is then a working stroke, and the flywheel obtains an impulse at every revolution. The pump is worked from the crank shaft, and the six operations are divided between it and the motor cylinder. The pump piston admits and compresses the charge, which is then exploded and expanded, and the products of combustion driven out from the motor cylinder. The two pistons work more or less simultaneously, and the forward stroke of the pump draws in the fresh mixture, during expansion of the charge in the motor cylinder. In other engines the pump is worked from a separate crank, set slightly in advance of the main crank. This cycle of operations is good, but its advantages are counterbalanced by the additional power required to drive the pump. Occasionally the gas and air are compressed into a separate receiver, and in a few engines the front part of the motor piston takes the place of the pump, and compresses the charge.

Oiling, &c.—Lubrication, starting, and regulation of the speed in a gas engine, each require a few words of explanation. Oiling the piston is a matter of much importance, and must be carefully performed. The high speeds and temperatures at which gas motors work necessitate a continuous and skilful use of good mineral oil. In steam engines there is generally a certain amount of water, but the flames of a gas engine dry the internal surfaces, and unless oil is continuously applied, the cylinder soon becomes hot and begins to suffer. Hence the importance of internal lubrication in all gas engines. They are usually fitted with a special apparatus for oiling the various parts automatically.

Small gas engines can be quickly started, but with larger powers the process is not always easy. The engine should be at work in a few minutes, and the inertia of the working parts has to be overcome. All the larger motors are provided with special means of starting, such as

a receiver, into which a reserve charge is compressed, a handle or cam acting upon the exhaust valve to keep it open, thus reducing the pressure in the cylinder, or a reservoir of compressed air. Sometimes a small auxiliary gas engine is used.

Regulation of Speed.—To regulate the speed of an engine is rather a complicated process, and is effected in a variety of ways. Many different kinds of governors are used, though the majority are constructed on the principle of a weight acting by centrifugal force. A common type is the ball governor, but pendulum and inertia governors are also employed, while many are made with weighted arms or levers. The governor is generally in connection with the gas valve, but sometimes with the exhaust, or with the valve for admitting the charge. The following are the usual methods of governing:—

1. By regulating the opening, more or less, of the gas admission valve.

2. By completely cutting off the supply of gas during a certain number of strokes.

3. By admitting more or less of the explosive charge at a time.

4. By acting on the exhaust valve and holding it open.

Sometimes two or more methods are used with the same engine, according to the greater or less fluctuations in the speed. To vary the quantity of gas within certain limits is an effectual check. But if a smaller quantity be admitted than will ignite when mixed with air, a certain amount of unburnt gas passes through the cylinder, and into the exhaust. The speed is reduced because there is no explosion, but the gas is wasted. To reduce the total amount of the charge admitted may have a similar result, and give a weak stroke. In some modern engines the governor acts upon the gas valve to cut off the supply entirely for a time, when the speed is too high. Air alone being admitted, there is no explosion.

Modern engines are usually governed on the "hit-or-miss" principle, or by cutting off the charge, except precision engines for driving dynamos, in which misses are not allowable. Sometimes in these the gas valve is so connected to the governor that a rich mixture enters if much power is required, and a poor mixture for small powers, or when running empty. However poor the charge may be, so long as it is highly compressed, ignition is practically certain. Sometimes the governor acts on the gas and admission valves, and "throttles" them at varying periods of the stroke, the quality of the charge being always the same, but its quantity varied, like the cut-off of a steam engine. This method is said to give longer expansion in proportion to admission, and therefore a better heat utilisation. For the maximum power and best indicator diagrams an engine should work at full load and the highest compression, because

with a smaller charge compression will be less, the size of the compression space being always the same. Engines so governed do not consume less gas or oil than others. Their allowable variations of speed are very small, and the governor must be delicately adjusted. In governing on the "hit-or-miss" principle the admission valve closes above a certain speed, below this speed it remains open.

The tendency in modern gas motors is to simplify construction, and reduce the number of parts. Where only two lift valves are employed, one for admission, the other for discharge of the gases, the governor is usually connected to the latter. Under normal conditions of speed the suction of the forward stroke lifts the admission valve, and allows the charge to enter. This valve closes as soon as compression begins, during the return stroke, and remains closed as long as the pressure in the cylinder is greater than that of the atmosphere. The opening of the exhaust valve reduces the pressure, and when the gases are all discharged the automatic admission valve rises, and a fresh charge is admitted. If the speed be too great the governor acts upon the exhaust valve, keeping it open. As no vacuum is formed in the cylinder during the return stroke, the admission valve remains closed, and no fresh charge can enter until the governor has released the exhaust. In oil engines in which the charge is admitted through an automatic lift valve, the action of the governor on the exhaust is generally sufficient to prevent any fresh mixture reaching the cylinder. To cut off entirely the admission of oil is an undesirable method, because the cylinder and vaporiser rapidly become too cool to work efficiently. It must be borne in mind that in both gas and oil engines the governor can act only by reducing, never by accelerating, the speed.

CHAPTER II.

HEAT "CYCLES" AND CLASSIFICATION OF GAS ENGINES.

CONTENTS.—Theoretical Cycle — Heat Efficiency — Classification of Gas Engines by Types.

Theoretical Cycle.—The word "cycle," derived from the Greek, has the same signification as circle. As applied to mechanical motors it denotes a series of operations, at the end of which the working agent returns to its original condition, as at starting. The celebrated French engineer, Sadi Carnot, was the first to use the word in this sense, and for convenience it has been retained. Engineers have agreed to designate as a "cycle" the successive operations taking place in a heat motor, though these can never form what is termed a perfect or closed cycle. In every heat motor the same phenomena are repeated each time the gas, steam, or other working agent is introduced into the cylinder. In this sense, therefore, a given cycle of operations is periodically performed in these engines. The heat generated passes into the engine cylinder to perform the work. That portion of heat which has not been utilised in the engine is transferred to a source of cold, and the difference between these two sources (of heat and cold) represents theoretically the heat expended in work. A working agent is necessary, to which the heat must be imparted, and from which it is withdrawn.

The theoretical cycle imagined by Carnot, and called after him, was a perfect cycle—that is, the heat generated was employed solely in doing work, and none was wasted. The medium or "power agent," steam, gas, &c., was expanded, a piston was propelled, a given amount of work performed, and a given quantity of heat transformed into energy to produce this work. As the piston returned, it compressed the agent, restoring by compression all the heat that had been expended in work. A perfect cycle was realised, since the whole heat was thus returned to its source, and the working agent to its original condition. In practice a perfect cycle is impossible. Whatever the agent employed, it can never really return to its original condition, and all the heat be refunded, because a considerable quantity is irrecoverably lost. Much heat will escape through the cylinder walls; some will be wasted owing to imperfect expansion, passing out into the exhaust, and some will be expended in the friction of the engine. The more nearly, however, an

engine approximates to the condition of a perfect cycle, and the more heat is expended in work on the piston, the greater will be the efficiency of the engine, and the higher the proportion between the useful work performed and the heat received.

Heat Efficiency.—It has been shown that the higher the temperature of the mixture of gas and air produced by combustion in the cylinder, the greater the pressure, and, therefore, the greater should be the force exerted on the piston. On the other hand, the lower the temperature of the discharged gases, the more heat will be expended theoretically in work. The heat efficiency is the ratio of heat turned into work to the total heat received by the engine. In practice this efficiency is always affected by waste of heat through various circumstances. Nevertheless, it is necessary to expand the gases as much as possible, because it is only by complete expansion that all the available heat can be utilised in doing work. If the gases are compressed by the return stroke of the piston, this heat will, theoretically, be refunded. Such a cycle of operations can, of course, be only obtained in theory, but in any case the more complete the expansion, the more the temperature and pressure of the gases discharged into the exhaust will be reduced. Less heat will be carried over from the cylinder, and more will remain to be utilised in it. Hence it is of the utmost importance to obtain as perfect a working cycle in a gas engine as possible.

Types of Engines.—Different authors have adopted different methods of classifying the various types of gas engines. An obvious, but not very satisfactory, way is to divide them into horizontal and vertical. As a rule, engines for large powers are horizontal, and for small powers vertical; but in England almost all sizes are made horizontal. There is said to be less vibration than in vertical engines, and greater power is obtained for a cylinder of the same size, but many foreign and some English makers are of opinion that the advantages of vertical engines outweigh their defects.

A more logical classification of gas motors, based on their internal working, is to divide them into engines drawing in the charge of gas and air at atmospheric pressure, and engines compressing the charge before ignition. This is the classification employed by the best authorities, and here adopted. In this way we get:—

Type { I. Non-compressing engines; and
II. Compressing engines.

Each of these types may be subdivided into classes *a* and *b*.

Type I., *Class a*, includes non-compressing motors drawing in and igniting the charge at atmospheric pressure. The force of the explosion drives the piston forward, and the return stroke expels the products of

combustion. This type of engine is also made double-acting, giving an explosion or motor impulse per stroke on each side of the piston, and all the operations of admission, ignition, and expansion are effected while the piston moves once out and back again. The gases are discharged at the end of the stroke. These double-acting engines are no longer used; the original Lenoir is the best example of the type.

Type I., *Class b*, also represents engines, chiefly vertical, which draw in and ignite the charge at atmospheric pressure. The piston is forced up from the bottom of the cylinder, and performs no work, not being connected to the crank. In the return stroke it is locked to the crank shaft, and descends only by the force of atmospheric pressure. This is the motor or working stroke. In a certain sense this class of engine is also double-acting, like Class *a*, the piston receiving two impulses per revolution; the first from the explosion of the gas below, the second from the pressure of the atmosphere above. The best representative of this type is the Otto and Langen engine. In one variety, the Bisschop, the piston is driven up with great force, but is permanently connected to the motor shaft, instead of being free during its ascent. Both these classes, *a* and *b*, of *Type* I., are now obsolete.

Type II. comprises all engines using compression, and, like the first type, is divided into two classes. *In Class a* the whole cycle of work, including compression, takes place in the motor cylinder itself, and in order to effect the various operations in one cylinder, it is necessary to sacrifice one complete stroke. Compression is obtained at the expense of power, and the piston moves twice backwards and forwards for every explosion or motor impulse given to the crank shaft. The well-known Otto engine is a typical example. At least three-fourths of all gas engines, and all oil engines now made, belong to this type.

In Type II., *Class b*, there is the same cycle of operations as in Class *a*, but instead of sacrificing a stroke of the motor piston, one or more pump cylinders are added. Admission of the charge in the pump, and expansion in the motor cylinder, are effected simultaneously; the return stroke in the pump compresses the charge, while the motor piston drives out the products of combustion, as in the Clerk engine.

There are very few engines which do not belong to either of these types. These are chiefly six-cycle engines, where the operations are similar to those described in *Type* II., *Class a*, but a third complete stroke is added, in order to cleanse the cylinder thoroughly of the products of previous combustion by what is called a "scavenger" charge of pure air. To avoid the difficulty of having only one motor stroke in six, these engines are sometimes made double-acting—that is, an explosion takes place alternately at either end of the cylinder at every third stroke. Thus there are two impulses for every three revolutions,

as in the Griffin engine. The action of these different types will be fully explained later on.

It must be remembered that, in describing the to and fro motion of the piston of an engine, and its action on the crank, there are always two strokes, the forward or motor stroke, and the return or exhaust stroke. The forward or out stroke is towards the crank, the return or in stroke is away from the crank. The position of the piston corresponding to the outer dead point is when it is nearest to the crank shaft, and that corresponding to the inner dead point when it is furthest away from the crank. These terms will be used in this work.

The following table exhibits the different types and their cycles. The engines are assumed to be horizontal except when otherwise mentioned :—

Type I.—Non-compressing.

	Cycle of operations.
Class a. One explosion per revolution — one cylinder. (Example, Lenoir.)	1. Forward or *motor* stroke—admission of charge of gas and air; ignition, explosion, expansion. 2. Return stroke—discharge of gases.
Class b (vertical only). One explosion per revolution — one cylinder. (Example, Atmospheric engine.)	1. Up stroke — admission of gas and air; ignition, explosion, expansion. 2. Down or *motor* stroke—discharge of gases.

Type II.—Compressing.

	Cycle of operations.
Class a. One explosion per two revolutions—one cylinder. (Example, Otto.) (Called the Otto cycle, or four-cycle.)	1. Forward stroke—admission of gas and air. 2. Return stroke—compression. 3. Forward or *motor* stroke—ignition, explosion, expansion. 4. Return stroke—discharge of gases.
Class b. One cylinder and one pump—one explosion per revolution. (Example, Clerk.) (With modifications, Oechelhaueser.)	1. Forward or *motor* stroke—in cylinder—ignition, explosion, expansion; in pump—admission of gas and air. 2. Return stroke—in cylinder—discharge of gases; in pump—compression.
Class c (double-acting). One cylinder, one or two pumps—two explosions per revolution. (Example, Koerting).	1. Forward *motor* stroke—in cylinder—ignition, explosion, expansion, exhaust; in pumps—compression and admission of gas and air. 2. Return *motor* stroke—same cycle of operations in working cylinder and pump.

The following classification has been adopted by Mr. Roots:—

Class I.—Non-Compression Engines (two types).

Type 1.	Power developed directly by explosion.	
,, 2.	,, ,,	indirectly by atmospheric pressure.

Class II.—Compression Engines (seven types).

Type 3.	One revolution.	With the aid of separate pumping piston.
,, 4.	,, ,,	Use of opposite face of working piston as pump.
,, 5.	,, ,,	Without a pump.
,, 6.	Two revolutions.	Ordinary Beau de Rochas cycle.
,, 7.	,, ,,	Modified B. de R. cycle, reducing the charge fired to increase expansion.
,, 8.	Three revolutions.	
,, 9.	Compound engines (Expansion in two cylinders).	

Class III.—Continuous Combustion Engine (one type).

Type 10.

This classification, illustrated by numerous drawings and descriptions of engines, is fully described in Mr. Roots' book, *Cycles of Gas and Oil Engines*. It is an exhaustive list, and under one or other of these ten types most internal combustion engines hitherto produced may be classed. For a student it is, perhaps, somewhat complicated, and the fundamental division into compressing and non-compressing engines adopted above is more easily remembered. The author's classification, however, scarcely represents modern gas engine work, as only compression engines are now made.

CHAPTER III.

HISTORY OF THE GAS ENGINE.

CONTENTS.—Early Combustion Engines—Hautefeuille—Huyghens—Papin—Barber—Street—Lebon—Brown—Wright—Barnett—Drake—Barsanti and Matteucci—Lenoir—Hugon—Schmidt—Beau de Rochas Patent.

Early Combustion Engines.—The earliest attempts to obtain motive power from heat were made by igniting inflammable powder, and utilising the force of the explosion thus generated. As a source of energy, this combustible powder was the first agent used; it preceded the production of coal gas, or steam. Strictly speaking, cannons are the oldest heat motors, and the principles on which they are constructed are identical with those of internal combustion engines. Heat is applied to explosive powder, and the combustion and expansion of the powder furnishes the motive force to propel a ball forward. In modern heat engines a piston takes the place of the ball. In the early days of mechanical science, the energy shown in the projection of a cannon ball seemed to afford a simple solution of the problem how to obtain power and motion by heat. But the power produced by exploding powder in a cannon could not be used for practical work, because it was not generated continuously and regularly. To apply the expansive force of the gases given off during combustion, the combustible was exploded in a closed vessel, and made to act upon a piston. These early combustion engines were the forerunners of modern gas motors, in which the power is also obtained by explosion. But though they were introduced nearly a hundred years before the first steam engine, they were soon abandoned, because it was found impossible to control the power generated. Steam was easier and safer to work with, and, for more than a century, explosive engines were wholly relinquished.

Hautefeuille.—The first to propose the use of explosive powder to obtain power was the Abbé Hautefeuille, the son of a baker at Orleans. To him belongs the honour of designing, not only the first engine worthy of the name, but the first machine using heat as a motive force, and capable of producing a definite quantity of continuous work. As such, he may be considered one of the originators of heat motors. In 1678 he suggested the construction of a powder motor to raise water. The powder was burnt in a vessel communicating with a reservoir of water. As the gases cooled after combustion a partial vacuum was formed, and the water was raised by atmospheric pressure from the reservoir. Another machine described by him in 1682 was based on the principle of

the circulation of the blood, produced by the alternate expansion and contraction of the heart. Here the water was raised by the direct expansive action of the combustible gases given off by the powder when ignited. This was the first instance of a direct-acting engine, but no machine could be made strong enough to resist the spasmodic expansion of powder, as here proposed.

Huyghens, Papin.—Hautefeuille does not seem to have actually constructed the machines he designed; but Huyghens, who was the first, in 1680, to employ a cylinder and piston, constructed a working engine, and exhibited it to Colbert, the French Minister of Finance. The powder in this motor was ignited in a little receptacle screwed on to the bottom of a cylinder. The latter was immediately filled with flame, and the air in it was driven out through leather tubes, which by their expansion acted for the moment as valves. The piston was forced by the pressure of the atmosphere into the vacuum thus formed. This is the action shown in modern atmospheric gas engines, but Huyghens found a difficulty in getting his valves to act properly, and in 1690 an endeavour was made by **Papin** to improve upon his principle. By providing the valves with hydraulic joints, Papin contrived to make them tighter, and to obtain a better vacuum, but he found that, in spite of all his efforts, a fifth part of the air still remained in the cylinder, and checked the free descent of the piston. After various attempts to overcome this difficulty, he abandoned the use of explosive powder, and devoted his attention to steam.

Barber.—For more than 100 years after these early attempts, all the efforts of scientific men and inventors were directed to the study of steam, and its applications to produce power. For the time there was no other known agent that could compete with it. Gas extracted from coal had not yet been applied as a motive force in engines, and experience had shown that explosive powders were too dangerous, and too intermittent in their action, to be used with safety. The first to design and construct an actual gas engine was John Barber, who took out a patent (No. 1833) in 1791. Various circumstances contributed to the success of his invention. The steam engine already occupied an important position in mechanical science, thanks to the genius of Watt, Newcomen, Smeaton, and others. Workmen had by this time been trained, able to turn out and adjust with fair precision the different parts of an engine, though good tools were still hardly to be obtained. The distillation of gas from coal had already been discovered by Dr. Watson, though it was not till 1792 that Murdoch, a Cornish engineer,* applied it to practical use. Barber made the gas re-

* The first practical application of gas to lighting purposes was in 1798 at the Boulton and Watt Soho Factory near Birmingham, where Murdoch was then employed.

quired for his engine from wood, coal, oil, or other substances, heated in a retort, from whence the gases obtained were conveyed into a receiver and cooled. A pump next forced them, mixed in proper proportion with atmospheric air, into a vessel termed the "Exploder." Here they were ignited, and the mixture issued out in a continuous stream of flame against the vanes of a paddle wheel, driving them round with great force. Water was also injected into the explosive mixture to cool the mouth of the vessel, and, by producing steam, to increase the volume of the charge. Barber's engine exhibits in an elementary form the principle of what is now known as combustion at constant pressure, but it had neither piston nor cylinder.

Street.—The next engine, invented by Robert Street, and for which he took out a patent (No. 1983) May 7th, 1794, was a great step in advance. Inflammable gas was exploded in a cylinder and drove up a piston by its expansion, thus affording the first example of a practical internal combustion engine. The gas was obtained by sprinkling spirits of turpentine or petroleum at the bottom of a cylinder, and evaporating them by a fire beneath. The up stroke of the piston admitted a certain quantity of air, which mixed with the inflammable vapour. Flame was next sucked in from a light outside the cylinder, through a valve uncovered by the piston, and the mixture of gas and air ignited. The explosion drove up the piston, and forced down the piston of a pump for raising water. In this engine many modern ideas were foreshadowed, especially the ignition by external flame, and the admission of air by the suction of the piston during the up stroke, but the mechanical details were crude and imperfect.

Lebon.—A great improvement in the practical application of gas engines was made by Philippe Lebon, a French engineer, who obtained a patent, Sept. 28, 1709, and a second in 1801. The first was more particularly intended to describe the production of lighting gas from coal; in the latter he proposed to utilise this gas to drive a piston in an engine very similar to that designed by Lenoir, sixty years later. The inflammable gas and "sufficient air to make it ignite" were introduced separately into the cylinder on both sides of the piston, and the inventor proposed to fire the mixture by an electric spark. The machine was double-acting, and the explosions of gas took place alternately on each side of the piston. The most striking peculiarity of the engine was the piston-rod, working not only the motor shaft, but through it two pumps, in which the gas and air were compressed, before they entered the motor cylinder. Lebon also suggested that the machine generating the electric spark should be driven from the motor shaft. The excellent theoretical principles on which this machine had been designed were striking at that early period, and marked a new era in gas engines. More than sixty years elapsed before the great

advantages Lebon had so clearly understood, of compressing the gas and air before ignition, were fully realised. The progress of mechanical science was perhaps retarded for many years by the assassination of this skilful engineer in 1804, before he had time to perfect the details of his invention. But in any case Lebon's engine was too much in advance of the times to have achieved immediate success. The manufacture of gas from coal was still in its infancy, and it was too expensive and difficult to produce to be used for driving an engine, while electricity was at that period so imperfectly understood, that the ignition of the charge by an electric spark was alone sufficient to condemn the motor.

Brown.—Lebon had many imitators, especially in France, but the next to invent a practical engine was an Englishman, Samuel Brown, who took out two patents, No. 4,874, in 1823, and No. 5,350, in 1826. Brown's gas engines were the first actually at work in London and the neighbourhood, and also the first in which the pressure of the atmosphere was utilised as a motive power. The principle in both was the same—viz., to produce a partial vacuum in a cylinder by filling it with coal gas flames, which drove out the air; the products of combustion were instantly cooled, and the vacuum thus obtained utilised to drive a piston. Instead of explosion, combustion of the gases was obtained by lighting them at a small flame as they entered the cylinder. The temperature of the latter was reduced by a water jacket, and water was injected to help the vacuum. In his first engine Brown employed two cylinders and pistons, connected by a beam. One piston was driven down by atmospheric pressure at one end of the beam, while the other, connected to the other end, was simultaneously raised. Part of the air escaped through valves in the piston, and the burning gases being instantly cooled by the water injected, condensation was produced, and a vacuum formed. In his second gas engine several cylinders were used to obtain a continuous vacuum. The working action was the same, but the air escaped through the valve covers of the cylinders, which were successively lifted. As in the other engine, the gases were cooled, after combustion, by the injection of water. These engines were, however, cumbrous and difficult to work, and the expense of driving them with coal gas soon stopped their manufacture. A drawing is given in Robinson's *Gas and Petroleum Engines*, p. 40, 2nd edition.

Wright.—The next improvement in gas motors was the use of a governor to control the speed, introduced by Wright in his vertical double-acting engine, patented 1833 (No. 6,525). Wright's engine had one cylinder and piston, and an explosion was obtained alternately at either end of the cylinder. The piston and piston-rod were hollow, and the cylinder had a water jacket to counteract the intense heat of the double explosion. Ignition was obtained by an external flame and a

touch hole. The gas and air were slightly compressed in separate reservoirs, before entering the motor cylinder; their admission was regulated by a centrifugal governor, and the richness of the mixture, or the greater or less quantity of gas passing the valve, varied with the speed. The design of this engine was carefully thought out, and its practical working details had not been overlooked, but it appears doubtful whether it was ever made.

Barnett. — Five years later, in 1838, William Barnett, another Englishman, took out patents for three vertical engines. These engines contained so many novel and interesting features, and anticipated in so many ways the latest improvements of modern science that they mark an important advance in the construction of gas motors.* The first (patent No. 7,615) had one working cylinder, single-acting. Gas and air were drawn in and compressed by two pumps, and passed into a receiver below the motor cylinder, where they were mixed. During the down stroke of the pumps, while the charge was being forced into the receiver at a

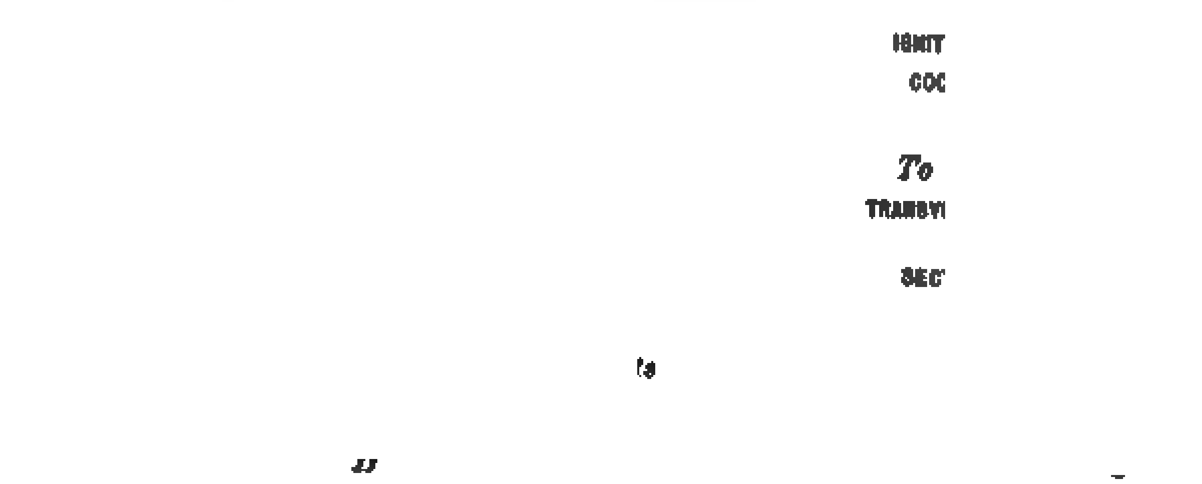


Fig. 1.—Barnett's Engine Gas Ignition Cock—Longitudinal and Transverse Sections. 1838.

pressure of about 25 lbs. per square inch, the return stroke of the motor piston was discharging the burnt gases through the exhaust. All three pistons moved simultaneously up and down. As the motor piston reached the bottom of its stroke, a valve at the side opened communication with the receiver. At the same time a revolving ignition cock immediately above the exhaust fired the mixture issuing from the receiver, and the burning gases entered the motor cylinder through the admission port, and impelled the piston upwards, as the crank passed the dead point.

The conical ignition cock, two views of which are shown in Fig. 1, is well designed, and has formed the type for many similar arrangements.

* A drawing of Barnett's engine is given in the *Proceedings of the Inst. Mechanical Engineers*, 1889.

It consists of a hollow revolving plug A in a shell B. There are two openings, *d* communicating with the outer air, and *e* facing the cylinder; the conical plug itself has only one port. At the bottom of the shell is a gas jet, which, when lighted, is in the centre of the hollow plug. As the plug revolves, the slit in it is brought opposite the port *e* of the shell communicating with the cylinder, and part of the highly-compressed gases passes into the hollow plug, and fires the charge. The flame itself is blown out by the force of the explosion; but, as the plug continues to revolve, the slit is brought to face port *d*, opening to the atmosphere, on the outside of which is a permanent second gas flame H. Here the light is rekindled, each time it is brought round by the revolving plug.

Barnett's second engine was double-acting, but in principle it resembled the first. The third engine in its mechanical details differed very little from the gas motors now in use, and modern inventors have found it difficult to improve upon it in theory. One defect of Barnett's former engines was that, as the receiver or charging cylinder was never swept out by the piston, a portion of the gases of combustion was not displaced by the new compressed charge of gas and air, but always remained in it. In Barnett's third engine both pump and receiver were abolished, and the gas and air were compressed in separate cylinders, and delivered direct into the motor cylinder. The engine was double-acting, and the compressed gas and air were admitted alternately to each face of the piston. The piston being at the bottom of the cylinder, the compressed charge below it was fired by the ignition cock, the piston drove up the products of combustion from the last explosion, and discharged them during the first half of the stroke into the atmosphere, through a port in the centre of the cylinder. As this port was closed by the piston, the pressure below it fell to that of the atmosphere. The gas and air from the pumps were then delivered into the top of the cylinder, and further compressed by the continued up stroke of the motor piston, together with a certain residual quantity of the gases of combustion. The mixture at high pressure was fired, and the piston in its descent first forced out the burnt gases below it, and compressed the remainder with the fresh charge during the second part of the stroke. At the bottom of the cylinder a fresh explosion took place, and the cycle was repeated.

Barnett may justly claim the honour of having been the first to introduce compression of the gas and air in a practical shape, as now used in gas engines. Lebon, it is true, proposed to compress the mixture slightly before igniting it, but he did not work out the details, or put his method to the test of actual practice. There are three points distinguishing Barnett's from previous engines. Ignition was effected at the dead point, and gave an impetus to the crank and piston during the whole

forward stroke; the gas and air were compressed before ignition; and part of the products of combustion were utilised to increase the pressure in the motor cylinder. It is generally admitted, however, that Barnett did not recognise the merit of his own suggestions. Experience has shown that compression is essential to economy in a gas engine, and ignition at the dead point is also important, but Barnett apparently used both without realising their value. Nor did he seem aware of the difficulties of disposing of the gases of combustion, a point on which later inventors have differed so widely; for although he attempted to discharge the greater part, he evidently did not regard the presence of the remainder as affecting the explosion of the mixture. In the opinion of Mr. Clerk, insufficient expansion was the fault of the later Barnett engine, a defect which it has been found difficult to avoid in double-acting motors.

Two or three smaller engines were designed during the next twenty years, although none of them seem to have been constructed. In 1841 Johnston described a motor in which he proposed to introduce oxygen and hydrogen gas into the cylinder, and fire them. The force of the explosion drove up the piston, and a vacuum was produced by the condensation of the gases. The same process was repeated at the top of the cylinder, and the piston was forced down by the fresh explosion, ascending and descending alternately in a vacuum. The great cost of these gases was sufficient to condemn Johnston's project.

Between the years 1838 to 1860 a large number of patents were taken out both in England and France, but most of the engines never advanced beyond the specification. Sixteen patents were granted from 1850 to 1860, a few of which are described below, because, as inventions, they are interesting.

Drake.—An ingenious gas engine was exhibited by Dr. Drake at Philadelphia in 1843; the English patent (No. 562) was taken out in 1855. In this horizontal engine ordinary lighting gas was used, mixed with nine or ten times its volume of atmospheric air. Much care was taken to admit the mixture in proper proportions, and the supply of gas was regulated by valves controlled by a governor. The charge entered the cylinder at atmospheric pressure, and was fired by a small tube kept at white heat by an external flame. The force of the explosion drove out the piston, giving a maximum pressure of about 100 lbs. per square inch; the mean effective pressure during the stroke, with a speed of 60 revolutions, and 20 indicated H.P.,* was about 36 lbs. per square inch. The cylinder had a water jacket, and the piston was hollow. The engine was afterwards modified, and worked chiefly with petroleum.

* H.P. = Horse-Power. I.H.P. = Indicated Horse-Power.
B.H.P. = Brake Horse-Power.

An important suggestion, which has since formed the basis of many successful engines, was made by Degrand in 1858. He proposed to compress the charge in the cylinder by the motor piston, but the idea was premature, and was abandoned at the time.

None of these engines worked successfully, and many were never made. One cause of their failure, which has not been much noticed by writers on the subject, was the difficulty of procuring lighting gas from coal, except in a few of the large towns. The art of distilling gas was still in its infancy, and possibly few of the early inventors foresaw the day when gas would become a household commodity, as easily obtained, even in small villages, as water. Sixty years ago it was costly and seldom available, and numerous substitutes, none of them very practical, were proposed. As gas was more extensively made it became much cheaper; engineers saw in it a new motive power, concentrated their efforts to utilise it, and finally achieved success. Another mistake made by the early inventors of gas motors was, that they attempted to supplant, instead of to supplement, the steam engine. They did not perceive the real advantages of the gas engine as a motor for small powers, but tried to make economical engines up to 20 H.P., or 50 H.P., before the constructive details were thoroughly understood. A third difficulty in constructing practical gas engines lay in the ignorance prevailing on the subject. They were designed too much on the lines of steam engines.* Most of the latter were double-acting, and the inventors of the day could not divest their minds of the idea that a similar method, if adopted with gas, would give the same favourable results. Experience has shown that the action of gas in a cylinder is very different from that of steam, and that gas engines must be differently designed.

Barsanti and Matteucci.—At about this period, however (1860), and especially after the production of the Lenoir and Hugon engines, three defects had come to be recognised as the inevitable results of an explosion at each to and fro stroke of the piston. The heat generated was so great that it had to be carried off as quickly as possible, and, even with water jackets to the cylinder, parts of the engine sometimes became red hot. It was also impossible, in a double-acting engine, to compress the gas and air before ignition; and lastly, expansion of the gases was greatly limited. The stroke of the piston was too short to utilise to the full the expansive force produced by the explosion, and the products of combustion were discharged at a pressure much above atmospheric. In this way almost all the heat generated by the ignition and explosion of the gases was wasted. Many experiments were made, and many engines constructed, before it was realised that the greater the amount of heat

* The present tendency in gas engine construction is to approximate to steam engine design.

utilised by doing work on the piston, the lower would be the temperature and pressure of the gases at discharge, and the less heat would be wasted. The next engine, invented by two Italians, Barsanti and Matteucci, showed a better knowledge of the principles of economy. In it a distinct step in advance was made, and an important principle exhibited for the first time in practice—namely, the use of a free piston, and unchecked expansion of the charge. For this reason their motor deserves attention and study, though, like many others, it was not a practical working success.

Two patents were taken out by Barsanti and Matteucci in England, the first in 1854, the second in 1857. In the first the free piston was supplemented by a lower auxiliary piston immediately below it in the same cylinder. An outline drawing of the engine is shown at Fig. 2. A is the cylinder and P the motor piston; *p* is the auxiliary piston, S the flat slide valve actuated by a lever F connected with the rod E of the auxiliary piston, which passes through the bottom of the cylinder. The crosshead at E is attached by two levers, not shown in the drawing, to the wheel D and the crank J, driven from the main shaft, but not revolving so rapidly. As soon as the free piston P has reached its lowest position, *p* begins to descend, and air is admitted between the two pistons through the passages *a*, *b*, *c* of the slide valve S. As the auxiliary piston descends, the slide valve is lowered with it by the lever F, the air port *a* is closed, and the gas port *d* uncovered, admitting gas to the cylinder between the pistons through *d*, *b*, and *c*. The slide valve next shuts off *d*, when the mixture is fired by a series of electric sparks, the circuit being put on by the lever F. The piston P, which has been at a stand, is now projected upwards, free of the crank shaft, and *p* is forced still lower, driving out the products of combustion below it through the openings *i i* in the bottom of the cylinder. The pressure in the cylinder beneath the free piston is now below atmosphere, the valves *i i* close automatically, the channel *f* is uncovered, and as the piston rises communication is established between the contents of the cylinder above and below the piston *p* through *f*, *e*, and *b*. The working piston descends in the

Fig. 2.—Barsanti and Matteucci's Gas Atmospheric Engine. 1854.

vacuum, driving out the exhaust, and the same process is repeated. This is the first instance of the slide valve, afterwards much used.

The arrangement of the catch is novel and ingenious. The rod of the free piston P carries a rack, and as soon as the piston begins to descend, the rack gears into the toothed wheel L, running loose on the main shaft K. The wheel L has a pawl C. As the rack falls, and drags L round to the right, the spring *s* presses the pawl C into the teeth of the ratchet wheel B, which is keyed on to the main shaft K, and causes B and therefore K to rotate to the right. When the piston rises the main shaft continues to turn to the right, but the movement of the wheel L is reversed; it revolves to the left with the up stroke of the piston, and C., slipping past B, loses connection with the main shaft.

In the second engine patented by Barsanti and Matteucci the auxiliary piston was abolished, the slide valve was worked by a valve-rod, and the details were much simplified. There was an auxiliary as well as a motor shaft, both having pawls acting upon the rack. In both engines a much better and freer expansion was afforded to the combustible gases than had hitherto been obtained. In fact there was no check to their expansion, except the weight of the piston, &c. But, notwithstanding its excellent cycle, this motor was never in the market, probably because the working details and the mechanism were defective. That the main lines on which it was constructed were good, is proved by the fact that they were adopted and successfully put in practice by Otto and Langen, though the German engineers appear to have designed their motor independently. The fundamental principle of the Barsanti and Matteucci engine, to utilise the whole force of the explosion in as complete expansion as possible, was excellent, and has not been improved upon. Few modern inventors have been able to approach as closely the conditions of a perfect theoretical cycle.

About the year 1860 the importance of the gas engine had become widely recognised. Great as was the perfection to which steam engines had been brought, it was felt that they did not, and could not, supply the various requirements for an economical motor. The necessity for some other kind of engine had already been pointed out by Cheverton in 1826. In a letter to the *Mechanic's Magazine* he says—"It has long been a desideratum in practical mechanics to possess a power engine, which shall be ready for use at any time, capable of being put in motion without any extra consumption of means, and without a loss of time in its preparation. These qualities would make it applicable in cases where but a small power is wanted, and only occasionally required. They are so numerous, and the consequent saving of human strength would be so great, that the advantages accruing to society would be immense, if even the current expense were much greater than that of

steam." No words could better describe the advantages of the gas engine.

Application.—In the history of gas motors three periods may be distinguished—1, Invention; 2, Application; 3, Theoretical and practical improvement. The first, the period of invention, was over. Hydrogen, inflammable powder, and other explosives were no longer used in engine cylinders, and gas was already recognised as the most suitable medium, next to steam, for utilising heat as a motive power. In the construction of the gas engine, much had been achieved by mechanical ingenuity. All the parts had been designed, and the details thought out. Scarcely a single improvement has been suggested in modern engines which may not be found in the drawings of Lebon, Barber, Street, Barnett, and others. In the words of Professor Witz—"The gas motor had been invented; the problem was how to make it a working success." It is here that we enter on the second period, that of Application. That time, too, has now passed. Practical experience has long been brought to bear on the construction of the gas engine, but the maximum utilisation of the heat is still a problem of the future.

Lenoir.—From this point of view, the honour of having invented and introduced the first practical working gas engine justly belongs to Lenoir. His specifications set forth no new features, but he was able, not only to make his engine work, which no one had hitherto succeeded in doing, but to work rapidly, silently, and, as at first supposed, more economically than steam. Cost and space were reduced by the absence of a boiler, and nothing could apparently be simpler, nor better suited to drive machinery of every kind, than the new motor. Its success was undoubted, and every one was eager to use it. It was made, however, at a time when very little was known of the theory of the gas engine, its action was imperfectly understood, and the economy with which the new motor was credited was soon found to be a fallacy.

Lenoir took out his first patent in France, Jan. 24, 1860; in England, No. 335, Feb. 8, 1860. The engines were made by M. Hippolyte Marinoni, a French engineer, whose mechanical skill undoubtedly contributed to their success. During the first year one was constructed of 6 H.P. and another of 20 H.P., and so great was the demand that, in five years, between three and four hundred motors were made in France, and a hundred in England. The construction of these was undertaken by the Reading Iron works in England, and the Compagnie Lenoir at Paris; in 1863 the patent of the latter was acquired by the Compagnie Parisienne de Gaz.

The usual reaction from undue praise and indiscriminate adoption of the new engine followed. The chief cause of its sudden fall in popular esteem was the discovery that it consumed much more gas than it was

said to do. In practice, from 88 to 105 cubic feet of Paris gas were burnt in the Lenoir engine per H.P. per hour. A brake experiment gave a mean of nearly 106 cubic feet, and this was about the average consumption for small powers. The quantity of water required for the cooling jacket was considerable. The heat generated was so great that unless the engine was copiously oiled the working parts were injured, and it was brought to a stand. Hence it was sarcastically said that "the Lenoir motor did not require heating, but oiling."

The sweeping condemnation bestowed upon these engines was hardly justified, for they possessed many advantages, which were as completely overlooked as their defects had been at first. They were easy to transport, to fix, and to set to work, and, when constructed for small powers, were very useful in many cases for superseding manual labour. They could be started at a moment's notice, and when not running, no expense for gas was incurred, while they have hardly been surpassed for silent, smooth, and regular working. But these were not the chief merits of the Lenoir engine. It was the first to compete with steam for small powers, and to familiarise the public with the idea of obtaining motive power from gas. The advantages of these motors were so great and so patent that, when the Lenoir was gradually superseded, it was replaced by other engines driven by gas. Its very defects acted as a stimulus to fresh efforts, and kept the subject before the minds of inventors. Once accustomed to the easy action of the gas engine, in which it was only necessary to turn a valve on the gas main, and another on the water supply, to set the machine in motion, many people refused to return to the laborious process of generating steam in a boiler.

Lenoir was himself fully alive to the faults of his engine, and continually studied to overcome them, but he started from a wrong basis. He attributed the extravagant consumption of gas to the rapidity of explosion, which affected the action of the engine injuriously, by producing a sudden rise and fall in the pressure. In common with later inventors, he endeavoured to diminish the force of the explosion, and to obtain a slower combustion of the gases by stratification, and in a second patent, No. 107, 1861, he proposed to inject a little water into the cylinder for this purpose. The injection of steam into a gas engine cylinder has since been often suggested, and put in practice; the subject will be considered later on. Lenoir himself does not seem to have carried out his proposal.

The much vaunted and much abused Lenoir gas engine resembled in construction a double-acting horizontal steam engine, and the gas was ignited electrically. Gas and air were admitted at both ends, drawn in by the piston during the first part of the stroke, then fired and expanded. Admission of the charge was cut off, either at half-

stroke or a little later. As ignition with the electric spark was sometimes retarded, it occasionally happened that the piston had passed through a considerable portion of the stroke before explosion occurred, and incomplete expansion was the result. The cylinder, both covers, and the chamber into which the gas was admitted, were water-jacketed, and the circulating water was used over and over again.

In the original drawing of the engine, shown at Fig. 3, A is the motor cylinder, in which is the piston P. The piston-rod works the connecting-rod C, and crank shaft K, through the crosshead D. Two eccentrics, G and H, on the crank shaft work two flat valves, S and S^1, on either side of the cylinder. The slide valves S S admit gas and air into the cylinder, and those at S^1 S^1 allow the products of combustion to escape. The latter each contain one exhaust port; and these are brought into line with the exhaust openings shortly before the end of the stroke, to discharge the gases of combustion, and close over them as the fresh mixture enters. Through the exhaust ports the gases pass into a discharge pipe, and thence into the atmosphere. The slide valves S S perform the functions of admission and distribution, and the two chambers L L are filled with gas. These valves are made with small cylindrical holes $\frac{1}{12}$ inch in diameter, alternating with larger apertures $\frac{1}{4}$ inch by $\frac{1}{2}$ inch diameter. The gas enters from L through these holes, while the air is admitted through the ends of the slide valves, which are open to the atmosphere, and passes through the apertures in the proportion of about 1 of gas to 12 of air. This arrangement of comb-shaped grooves and passages is continued throughout the whole thickness of the slide, and the effect is to cause the gas and air to flow to the cylinder in separate streams. By thus forcing them to enter without mingling, a better stratification of the charge was supposed to be obtained, but this appears doubtful. At either end of the cylinder is a small projection at b and b^1, to which wires are attached from the coil and electric battery M.

The action of the engine is as follows:—The exhaust valves being closed when the piston is at the extreme end of the stroke, as shown in the drawing, the energy of the flywheel is sufficient to carry it forward. The air port (which is very large to prevent throttling) is already slightly open, the gas valve now opens, and the charge is mixed in the main port of valve S, before being drawn into the cylinder by the forward stroke of the piston. Meanwhile the pressure on the other side of the piston has been reduced to that of the atmosphere. Before the admission valve is completely closed the electric spark fires the mixture, and the piston is thus propelled forward to the end of the stroke, the pressure rising to 5 or 6 atmospheres, but the action of the water jacket cools the cylinder, and reduces the pressure. The exhaust valve has a slight lead, and opens a little before the end of the stroke, allowing the

gases of combustion to escape at a pressure of 1·5 to 1·8 atmosphere. The same process is repeated during the return stroke. A certain

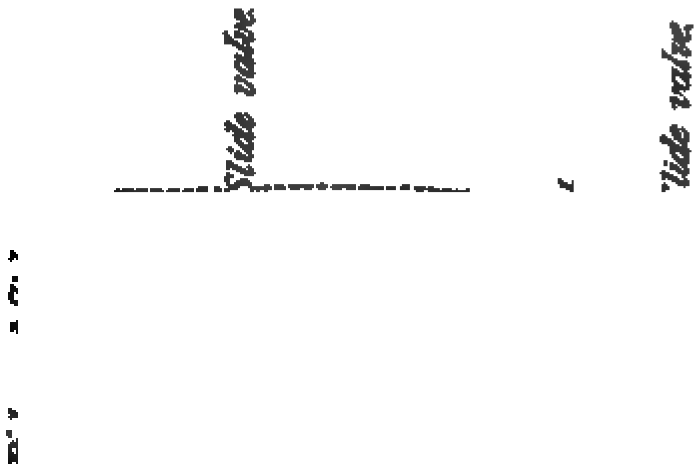


Fig. 3.—Lenoir Horizontal Engine. 1860.

proportion of the gases of combustion is always left in the cylinder, but their pressure is low, and the clearance spaces are very small. The

temperature of the escaping gases is given by Professor Schöttler at about 200° C. In an experiment by Tresca it was 220° C.

Fig. 4 gives a sectional plan of the cylinder, in which the admission of gas and air are slightly modified; the parts are lettered as in Fig. 3. Here the main admission port is open to the atmosphere, and is covered with a perforated brass plate, which extends downwards, so as also to cover the gas port. As the gas enters, it is forced to pass up and down through small holes in the metal plates, and to mix thoroughly with the air before entering the main port, but this arrangement, like that already described, was not found to work quite satisfactorily.

Air

Fig. 4.—Lenoir Engine—Section of Cylinder. 1860.

Like most of the early gas engines, the Lenoir was ignited by an electric spark, as shown at M, Fig. 3. A battery with two Bunsen cells, connected by a Ruhmkorff induction coil and an electric hammer, produces a continuous stream of sparks. The contact maker N is in connection with the crosshead D and piston-rod, through which the negative current passes, and the mass of the engine is negative. The positive current passes through wires insulated in porcelain tubes, leading from the two ends of the contact maker to the two projecting points, b and b_1, at each end of the cylinder. Contact is formed alternately between them by a projection moved to and fro by the crosshead.*

The speed of the engine was regulated in the ordinary way by a centrifugal governor acting on the gas admission valve, and the supply of gas was wholly cut off, as soon as the speed exceeded the normal limits. The oiling was always defective. Ordinary lubrication by hand was at first used, but this was soon found insufficient to counteract the great

* In the Lenoir Engine, as then made at the Reading Iron Works, this electrical arrangement was modified.

heat generated in a double-acting gas engine. The piston frequently became red hot and heated the incoming charge *before* ignition, a defect which later inventors have always carefully endeavoured to avoid; and the temperature was so high that, unless frequently and copiously oiled, the engine would not work.

It was always less difficult to start a non-compressing gas engine fired electrically than a compression engine, and the Lenoir motor was very easily set in motion. The flywheel was turned by hand, and the piston moved forward, drawing in the explosive mixture. At the same moment electric contact was established, a spark fired the charge, and the explosion drove out the piston over the dead point, after which the engine worked automatically.

The earliest trials on record of any gas motor are those made by Tresca in 1861 on the Lenoir engine. The first experiments were on an engine of ½ H.P. with a speed of 130 revolutions per minute. The proportion of gas to air was one-tenth, the maximum pressure obtained 4·87 atmospheres, the consumption of Paris gas was 112 cubic feet per H.P. per hour. In a second trial of a 1 H.P. engine, the quantity of gas used was reduced to 96 cubic feet per H.P. per hour, or about five times the average present consumption. The maximum pressure in the cylinder was 4·36 atmospheres, number of revolutions 94, and the proportion of gas to air 1 to 7½. In both engines more than half the total heat was carried off in the water jacket, and Tresca calculated that only 4 per cent. was utilised in useful work, the remainder being discharged with the exhaust gases. Other experiments were made by Lebleu, Eyth, and Auscher, and by Mr. Slade in America. Fig. 5 shows an indicator diagram of the Lenoir engine.

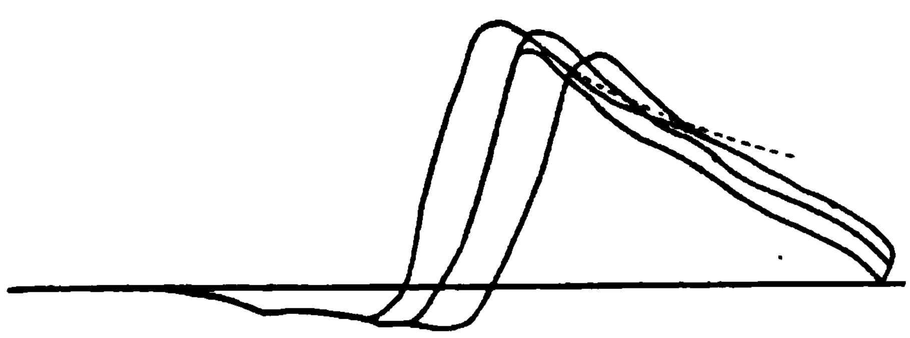


Fig. 5.—Lenoir Engine—Indicator Diagram (Slade). 1860.

Twenty-five years later Lenoir, who was incessantly endeavouring to perfect his invention, brought out a single-acting compression engine, using the Beau de Rochas' four-cycle. It will be described among modern motors.

The success of the Lenoir engine produced a host of imitators and rivals, several of whom set up a prior claim to the invention. Reithmann, a watchmaker at Munich, declared that he had designed an engine similar to Lenoir's, for which he had taken out a patent, September 11, 1858. It was described in the "Bayerische Kunst- und Gewerbeblatt," but, if ever

made, it never reached a practical stage. A more formidable opponent was Hugon, the Director of the Paris Gas Company, whose original patent also dates from September 11, 1858. It is certain that Lenoir worked independently, and that his invention as a practical engine was the first in the market.

Hugon.—Hugon's vertical gas engine did not appear till 1862, and he soon abandoned it in favour of a direct-acting engine similar in principle to Lenoir's, which he patented in France in 1865 (No. 66,807).

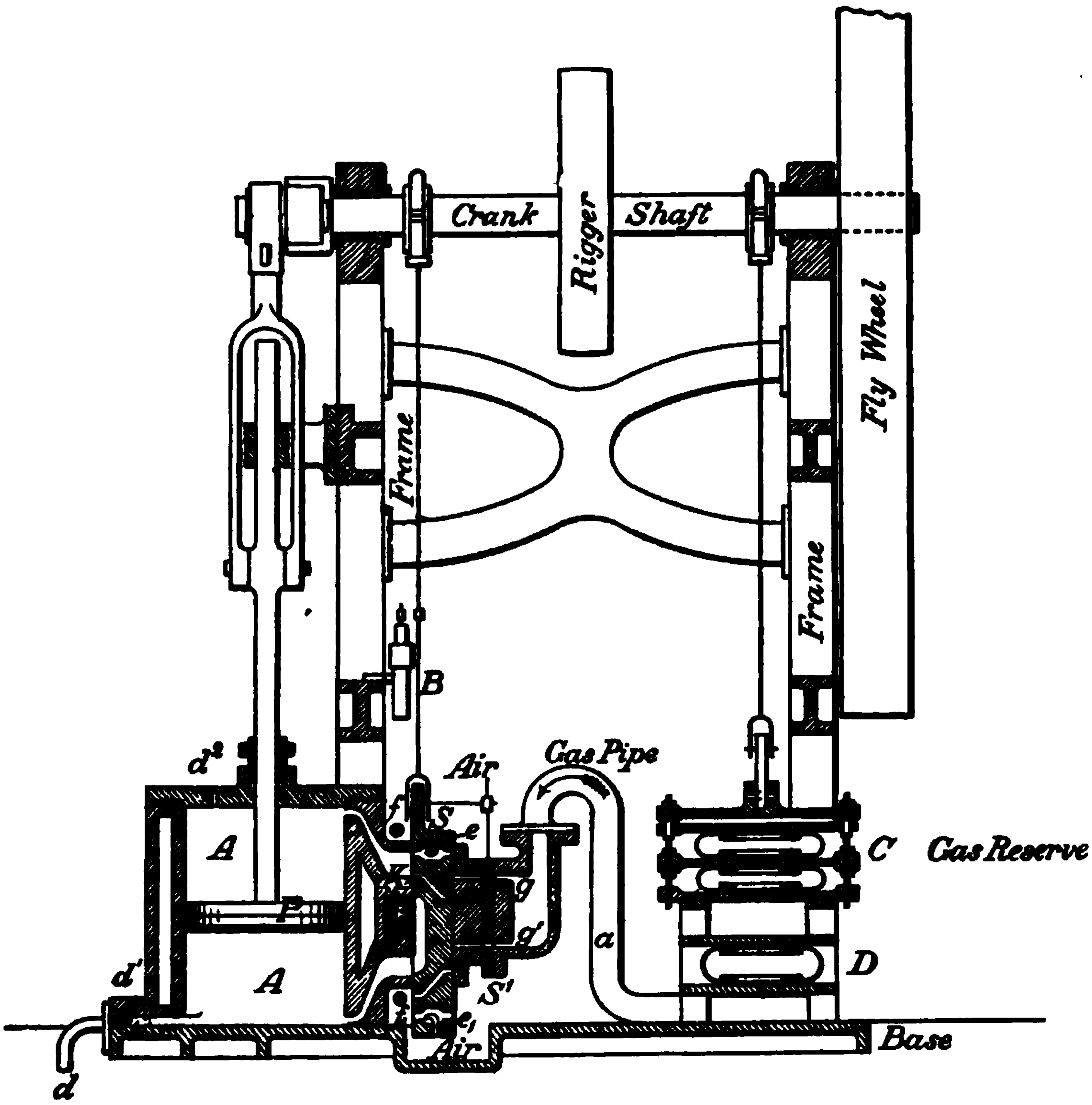


Fig. 6.—Hugon Gas Engine—Vertical. 1862.

Flame ignition was substituted for electricity, and a small quantity of water was injected into the cylinder at every stroke. The flame was carried to and fro in a cavity inside a slide valve, and the engine afforded the first practical illustration of this method of ignition, afterwards so generally used. The consumption of gas was still very high, and the engine did not find much favour, even in France.

In this vertical, single-cylinder, double-acting motor, air and gas at atmospheric pressure are admitted, as in the Lenoir, on both sides of the piston. The piston P and piston-rod in cylinder A drive the shaft

through a forked connecting-rod and crank, as shown in Fig. 6, taken from Schöttler's* careful description of the engine. An eccentric on the same shaft works the rubber gas reservoir C, from which the gas is pumped under slight pressure through the pipe *a* to the cylinder. A smaller gas reservoir D supplies gas for the ignition flames. The valve-rod, actuated by a second eccentric on the crank shaft, works the two admission valves S and S_1. A small pump B is driven from it, and injects water into the cylinder through the supply pipe *d* and the small openings d_1 and d_2. The main slide valve S has five openings—*e* and e_1, the igniting ports containing the two gas jets for lighting the mixture at each end of the cylinder; *g* and g_1, the admission ports which receive the mixture of gas and air from the tube *a*, through the openings in the auxiliary slide S_1; and *h*, the exhaust valve discharging through K into the atmosphere. In the second and smaller slide valve S_1, there are only two ports for opening communication between the main slide valve and the gas reservoir C, and by its action the sudden admission and cut-off are obtained, which form a principal feature of the Hugon engine; *f* and f_1 are permanent gas jets to rekindle the flame at *e* and e_1 when blown out, as it is each time, by the force of the explosion. There are two main ports, serving alternately for admitting the charge to the cylinder and igniting it, and for discharging the gases of combustion into the exhaust; this arrangement has since been altered.

The action of the engine is as follows:—When the piston is at the top of its stroke and begins to descend, the principal slide valve S is driven down, and the port *g* comes immediately opposite the upper main cylinder port, forming a connection between it and a port in the outer slide valve S_1, admitting gas and air from C through *a*. At this part of the stroke, the position of the slide valves is the following:—The light at *e* is in process of kindling by *f*, *g* is opening on to the main port, while at the bottom of the piston the products of the last explosion are discharging through *h* into the exhaust. The port *g* being much smaller than the main port, the supply of gas and air through S_1 is soon cut off, but the communication of *g* with the main port is still open when the slide is suddenly driven down by the movement of the eccentric on the shaft. The gas flame *e* is brought opposite the inflammable mixture, and spreads through it, and back into the admission port. Explosion takes place when the piston has passed through about four-tenths of the stroke, and drives it down through the remainder. The piston and slide valve now begin to rise, and the same process is repeated at the lower end of the piston and cylinder. As, however, the valve in its upward progress must again cross the admission passages in slide S_1 before reaching the top of the cylinder, gas and air would be admitted at the wrong moment, and

* Schöttler, *Die Gas Maschine*, 2nd edition, p. 23.

rapid admission and cut-off could not be obtained, unless this valve were closed. It is driven down by the pin projecting from the main valve, which catches and carries it in the same direction. A spring then holds it in position, and does not release it until the slide S has begun to return. The engine was tested by Tresca in 1866-67. Fig. 7 gives an indicator diagram of a trial by Mr. Clerk.

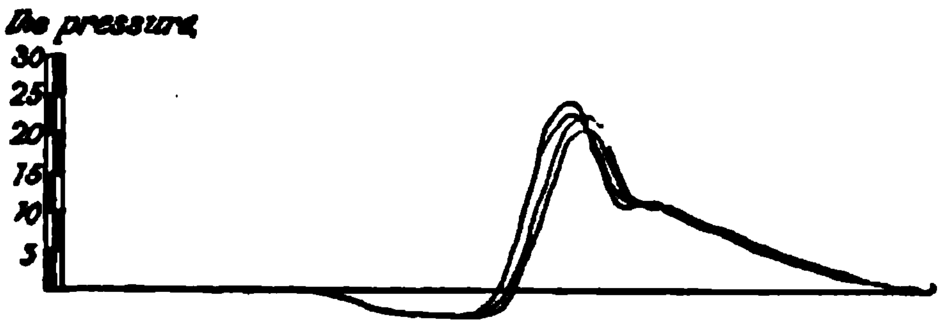


Fig. 7.—Hugon Engine—Indicator Diagram. 1862.

Siemens.—About this time the subject of heat motors engaged the attention of Sir William Siemens, and he took out several patents for gas and hot air engines. His regenerative engine is described in Chap. xviii.

The defect of both the Hugon and Lenoir engines was the large consumption of gas in proportion to work done. This extravagance checked the sale of these engines, and they ceased to be extensively made, even before others had been invented to take their place. Their failure was attributed to want of stratification. Inventors long thought it possible to distribute the admission of the charge in such a way that the gas and air were introduced either in separate layers or thoroughly mixed. Both Lenoir and Hugon were of opinion that the shock given by the explosion was too violent, and needed to be weakened. These erroneous notions were gradually abandoned, and the real reasons of the want of economy were at last perceived—namely, insufficient expansion, and the absence of compression.

Schmidt—Million.—In 1861 Gustave Schmidt, in a paper submitted to the Institution of German Engineers,* declared that more favourable results would be obtained, greater expansion, and better transformation of the heat of combustion into work, if the gas and air were previously compressed to two or three atmospheres. In the same year Million either re-discovered or was the first to apply Lebon's and Barnett's idea of previous compression of the gas and air by means of a separate pump. His proposals helped to develop the theory of the gas engine, but he does not seem to have put them into practice.

Thus the principle of compressing the charge of gas and air in an engine before ignition had already been foreshadowed, when a very remarkable descriptive patent upon the subject appeared in France in 1862 by M. Beau de Rochas. Hitherto the construction of gas engines

* *Zeitschrift des Vereines deutscher Ingénieure*, 1861, p. 217.

had not been designed and worked out on a scientific basis. Inventors did not fully understand the effect of the different operations they proposed to carry out. They were ignorant of the reason why one engine gave more economical results than another, and what methods should be adopted to control the extravagant consumption of gas. They were ready to recognise, without being able to remedy, the defects of their engines. Nor were study and perseverance wanting. Many of the earlier gas motors were the result of much labour and repeated experiments, and failed only for lack of a scientific comprehension of the subject.

Beau de Rochas.—The real reasons of the uneconomical working in the Lenoir and other motors were want of compression, incomplete expansion, and loss of heat through the walls.* In both the Lenoir and Hugon engines the pressures in the cylinder were always low and difficult to maintain, and this showed that the pressure generated by the explosion alone was insufficient, and must be increased by previous compression of the charge. Time was also lost in obtaining an explosion, and the heat, applied too late to the gas, was speedily dissipated, some of it going to heat the jacket water, and some being discharged at exhaust. M. Beau de Rochas, a French engineer, was the first to formulate a complete theory of the cycle of operations which ought to be carried out in a gas engine, to utilise more completely the heat supplied. Four conditions were laid down by him as essential to efficiency—

I. The largest cylindrical volume, with the smallest circumferential surface.

II. Maximum speed of piston.

III. Greatest possible expansion.

IV. Highest pressure at the beginning of expansion.

These working conditions are now generally admitted to be necessary, but at that time they created a revolution in the study of the gas engine. The first shows the reason why the consumption of gas was so much greater in small, as compared with larger engines. On this subject Mr. Dugald Clerk says, "As an engine increases in size, the volume of gaseous mixture used increases as the cube, while the surface exposed only increases as the square; so that the proportion of volume of gaseous mixture used to surface cooling is less, the larger the engine."

In the second and third conditions increased expansion and speed are insisted on. It was already known, or at least surmised, that unless the gases were as completely and quickly expanded as possible, much of the energy generated in the explosion was wasted. Only a small proportion

* The two latter defects, although to a certain extent controllable, are found more or less even in modern gas motors.

was expended on the piston in doing work, and the gases escaped at too high a pressure. It was evident also, since small cylinder wall surfaces were desirable, that the more rapidly the piston performed its stroke, the less time were the hot gases exposed to their action. "Other things

Lenoir.

Beau de Rochas.

Dugald Clerk.

Atkinson.

Fig. 8.—Gas Engine Pioneers.

being equal," says Beau de Rochas, "the slower the speed the greater the cooling." Moreover the higher the speed of the piston, the more rapid will be the expansion.

In Beau de Rochas' fourth condition a principle was embodied which contains the essence of the question, and the true secret of economy in a gas engine. The utilisation of the elastic force of the gases by prolonged expansion depended upon the high pressure of the charge, and

this pressure could not be realised unless the gas and air were compressed previous to ignition. Compression was to be effected while the gases were cold, and the heat thus applied prolonged the expansion by increasing their pressure. By thus compressing the particles, an originally larger volume of the charge, containing more gas, can be introduced per stroke into the cylinder, and the pressure of explosion considerably raised. The advantages of compression are shown by the fact that the greater the pressure, and the more instantaneous the admission, the greater the economy within certain limits.

Beau de Rochas' Cycle.—To obtain these results Beau de Rochas considered it necessary to use one cylinder only, first, that it might be as large as possible, and secondly, to reduce the piston friction. In this cylinder the following cycle was to be carried out in four consecutive piston strokes:—

I. Drawing in the charge of gas and air.
II. Compression of the gas and air.
III. Ignition at the dead point, with subsequent explosion and expansion.
IV. Discharge of the products of combustion from the cylinder.

By ignition of the charge at the dead point, the crank obtained the benefit of the impulse communicated by explosion and expansion during the whole of a forward stroke. This was not, however, the object specially aimed at by Beau de Rochas. He proposed to compress the gases to such an extent that they ignited spontaneously at the dead point. In almost all modern gas engines ignition at the dead centre is now considered essential, though it has generally been found difficult to ignite the gases by compression only. Each of the four operations generally requires one stroke of the piston, though in some cases compression is obtained in a separate pump.

This cycle, known as the four-cycle of Beau de Rochas, is the one now chiefly used in gas motors. It differs from that of Carnot because it is not a perfect or theoretical, but a practical, cycle. Many improvements have been effected in the mechanism of the gas motor, but they have all been founded on the sequence of operations and the working conditions described by Beau de Rochas. Next to compression, the most valuable innovations introduced by him were, carrying out all the operations in a single motor cylinder, and ignition at the dead point. But like many other scientific innovators, Beau de Rochas was in advance of his time. Fifteen years elapsed before what Professor Witz aptly calls "the programme traced of what ought to be attempted" was actually adopted, although now its merit is universally recognised and the cycle employed.

An award was presented to the veteran worker by the Société d'Encouragement pour l'Industrie Nationale in recognition of his valuable labours to advance the knowledge of the gas engine, and another by the Académie des Sciences. M. Beau de Rochas died in 1892. A translation of that part of his patent which relates to gas engine cycles will be found in the Appendix. On p. 39 the portraits are added of MM. Lenoir and Beau de Rochas, Mr. Dugald Clerk, M.I.C.E., and Mr. Atkinson, four distinguished men who have greatly contributed to our knowledge of gas engines.

CHAPTER IV.

HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—Otto and Langen Engine—Gilles—Bisschop—Brayton—Simon—Clerk Two-Cycle Engine—Beck Six-Cycle Type—Wittig and Hees—Compression—Martini Early Gas Engine—Tangye—Various—Baldwin.

THE construction of gas engines was meanwhile developed in a different direction to that indicated by Beau de Rochas. As it was seen that the expansion in the engines hitherto produced was insufficient, an attempt was made to improve it by employing a free piston, giving in theory unlimited expansion. At the Paris Exhibition of 1867 attention was drawn to an engine patented by MM. Otto and Langen in 1866, and apparently of a new type, though it was really constructed on the same lines as that of Barsanti and Matteucci. It seems doubtful whether this new engine was more or less copied from the Italians' atmospheric motor, or whether the Germans worked independently. In any case they succeeded in making a practical engine, based on a principle which, owing to some mechanical defect, had been relinquished.

Otto and Langen.—In their main features the German and Italian engines were identical. At that time the idea was prevalent that the failure of the Lenoir and Hugon engines was due to the slow movement of the piston after ignition. Scientific men were agreed that the energy generated by explosion was rapidly diminished by the cooling action of the walls; if therefore expansion was retarded, much of the force obtained was dissipated. Hence, the principle of the Otto and Langen engine was to obtain the most rapid and complete expansion possible after explosion. Theoretically this idea was right, but the mechanical difficulties of working it out have never been completely overcome, and though the construction of the engine was continued for some years, it was eventually abandoned.

At the time of its first appearance, the Otto and Langen was the most economical engine yet introduced. Its consumption of gas, always comparatively low, was ultimately reduced to about 26 cubic feet per H.P. per hour. About 5,000 motors were constructed in ten years, and though never popular in France, the engine was at one time in great demand in England and Germany. As a practical working motor it was not satisfactory, but it marked an epoch as the first single-acting engine, and the first in which economy in consumption of gas was realised as a

consequence of better expansion. It was, however, large for the power generated, noisy and irregular in action, and the very rapid ascent of the piston caused so much vibration, that it could only be used for small powers.

Otto and Langen, Single-Piston Atmospheric Engine.—Fig. 9 gives a sectional elevation of this engine. A is the long vertical cylinder, surrounded at the bottom with a water jacket, and open at the top to the atmosphere. P, the piston, is shown almost at the end of the down stroke. C is the rack in lieu of a piston-rod, gearing into the toothed wheel T on the main shaft K. The slide valve S, worked by an eccentric O, admits the gas and air, which are ignited by a flame in the slide valve cover, and also discharges the products into the exhaust pipe. There are two eccentrics side by side, O and B; both are connected to the auxiliary shaft M during the down stroke, but run loose on the up stroke of the piston. In the same way the wheel T, which is also free of the shaft during the up stroke, becomes wedged to it by an ingenious clutch arrangement as the piston descends. The action of the Otto and Langen engine necessitates the use of three special mechanisms, the friction coupling or clutch gear, on the outer wheel T of the main shaft, the device for lifting the piston to admit a fresh charge, served by eccentric B, and the valve motion driven by eccentric O.

Fig. 9.—Otto and Langen Vertical Engine—Transverse Section. 1866.

The violence of the explosion in a free piston engine is so great, that much care is necessary to make the clutch act freely and instantaneously. At the moment when the movement of the piston is reversed, the whole energy of the engine being stored up in it, the least recoil might result in an accident. This was one reason why the Barsanti and Matteucci engine failed; the ratchet and pawl were not sufficiently prompt in action. The clutch gear of the Otto and Langen engine, shown at Fig. 12, was the

result of careful study, and formed one of the most ingenious parts of the engine. Upon the main shaft K there is a circular disc *a*, which is solidly keyed to it, and carries on its outer edge at *e* four steel wedge-shaped slips or projections. The inner rim of the outer toothed wheel T is hollowed out in four places at regular intervals, just below the bolts *d*, and corresponding to the steel wedges *e* upon the disc *a*. In each of the grooves thus formed are three small cylindrical rollers. The main shaft

Fig. 10.—Eugen Langen.

K revolves always in the direction of the hands of a clock. When the piston flies up with the force of the explosion, and drives round the toothed wheel T in the opposite direction, the rollers run loose in the open space in the wider part of the hollows, and no pressure being exerted on the wedges *e*, the connection between the main shaft K and the rack, piston, and outer toothed wheel T is severed. The piston having reached the end of the up stroke, begins rapidly to descend (motor stroke), the motion of T is reversed, and it also revolves in the same direction as the motor shaft. The rollers are driven forward into the narrowest part of

the space, and wedged against the steel slips *e*, which grip the solid disc *a*, and the whole mass from T to K is driven round in the direction of the descending piston. The cooling of the gases below the piston forms a vacuum, but this is counteracted near the end of the stroke by the opening of the exhaust. Slight compression of the gases of combustion takes place at the bottom of the cylinder, and the motion of the piston is slackened. The toothed wheel T, therefore, revolves more slowly than the main shaft and disc *a*; the rollers run back, and loosen their grip of the wedges, and

Fig. 11.—Nicolas Otto.

before the piston has reached the end of the stroke, the motor shaft is again disconnected.

The working of the eccentrics driving the slide valve S is also shown at Fig. 12. The valve is somewhat similar in principle to Hugon's flame ignition valve, but more simple, as only one ignition per up stroke or per revolution is required. There is one main port *i* (Fig. 9) leading to the cylinder, and just above it are two small openings, *h* and *j*, for admitting the gas and air. In its lowest position the slide valve port forms a com-

munication between *i* and the atmosphere, the exhaust outlet in the valve cover being closed by a flap valve, which is lifted only when the pressure in the cylinder is greater than the atmosphere—namely, when the piston has nearly reached the bottom of its stroke. The products of combustion being thus discharged, the slide S worked by the eccentric O begins to rise, and the piston with it, lifted by the other eccentric B; gas and air enter through *j*, *h* in the proportions of 9 to 1, mix and pass through to the cavity *m*. Communication is now made between *m* and the outer permanent flame *f*, and the mixture of gas and air is ignited. The upward progress of the valve shuts off the flame at *f*, and the burning gases being brought opposite the main port *i* rush into the cylinder, explode, and drive up the piston.

The movement of the two eccentrics O and B is given by the auxiliary shaft M, on which is fixed a ratchet wheel W. The

T

Fig. 12.—Otto and Langen Engine. 1866.

eccentrics are set to each other at an angle of 90°, and run loose on the shaft during the down stroke. Eccentric O carries the rod working the slide valve S, B has a bell crank *r* working on a pivot, and a lever N, and these establish the connection between the eccentrics and the auxiliary shaft. The gases being ignited at low pressure, the ignition by flame, as in all non-compressing engines, worked satisfactorily. The speed was regulated by a ball governor. If the speed of the engine exceeded the proper limits, the governor, by means of a pawl and ratchet, disconnected the levers working the slide valve and piston, and no charge was admitted until the speed was reduced.

As the engine was single-acting, working open to the atmosphere, the heat generated was not so great as in the earlier motors. The

number of strokes per minute being relatively small, the cylinder was kept comparatively cool. It was not difficult to start the engine, a few turns of the flywheel being sufficient to draw in the charge, and cause it to ignite. The action of the walls, which has so injurious an effect in most engines, was here of use. During the upstroke the walls, by rapidly cooling the expanding gases, assisted in forming the vacuum, while in the down stroke they carried off the heat, and retarded the increase of pressure below the piston.

A number of experiments have been made upon the Otto and Langen engine. Of these the best known is Tresca's trial at the Paris Exhibition, 1867, on a half H.P. engine, when the consumption of Paris gas was 44 cubic feet per I.H.P. per hour. Another series of experiments was made in 1868 by Meidinger in which the gas consumption per H.P. per hour varied from 49 to 29 cubic feet.

Fig. 13 shows a diagram taken during a trial made by Mr. Dugald Clerk.

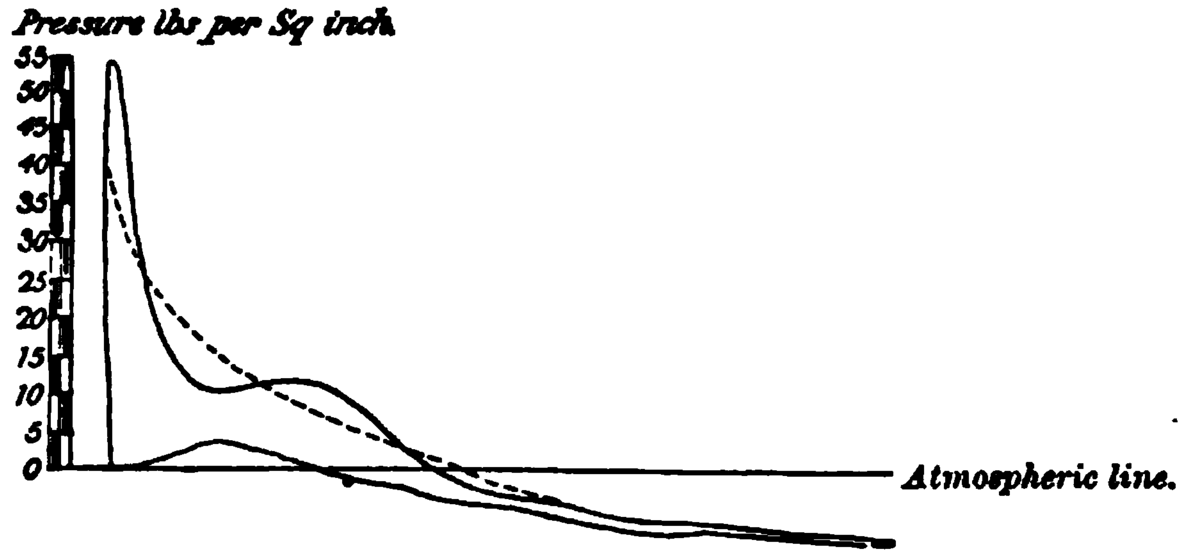


Fig. 13.—Otto and Langen Engine—Indicator Diagram (Clerk). 1866.

The great defect of the Otto and Langen engine was its noisy and unsteady action, due to the rack and wheel, and the excessive vibration and recoil. Several efforts were made in the course of the next few years to improve upon it, though the working principle remained the same.

Gilles.—In 1874 an engine was brought out by Gilles, with two pistons working vertically, one above the other, in the same cylinder; the lower was the motor, and the upper the free piston. The explosion of the gas and air drove up the latter; the working piston was forced up into the vacuum thus formed by the pressure of the atmosphere. Two drawings of the engine will be found in Schöttler's book.

Bisschop.—A useful little engine for small powers, which was popular for many years, although now no longer made, was introduced in 1870-72 by Bisschop, and exhibited at Paris in 1878. It appeared about four years after the Otto and Langen non-compression atmo-

spheric engine, and resembled that type of motor in principle, but was intended specially to avoid the noise and recoil of the free piston, rack and clutch gear. The charge of gas and air was admitted at atmospheric pressure, and the force of the explosion drove up the piston, but it was attached in a special way to the crank, and did not run free. The pressure of the atmosphere, and the energy stored up in the flywheel, then forced the piston into the vacuum formed below by the cooling of the gases. The action of the walls was turned to good account by reducing the temperature of the exhaust

Fig. 14.—Bisschop Engine—Sectional Elevation. 1870.

Fig. 15.—Bisschop Engine—Section of Piston Valve.

gases, and helping to form the vacuum. In a certain sense the Bisschop, like other atmospheric engines, may be called double-acting, the force of the explosion being used on one side of the piston, and the pressure of the atmosphere on the other.

The engine had a vertical unjacketed cylinder closed at both ends, and ribbed externally to prevent overheating. Above was a crosshead from which the connecting-rod worked direct on to the motor shaft, and was parallel to the piston-rod during the up stroke. Explosion occurred immediately after the piston had passed the lower dead point. The shock forced up the piston rapidly, the crank was carried round through more than half a revolution, and expansion was practically instantaneous. The distribution of the gas and air and

the discharge of the exhaust gases were effected by a trunk piston valve, driven from an eccentric on the crank shaft. Ignition was by an external flame, and the little engine had no governor.

Fig. 14 gives a sectional elevation, and Fig. 15 a section of the piston valve. The parts are lettered alike in the two drawings; the piston valve admits, distributes, and expels the charge. A is the motor cylinder and P the piston, *c* is the connecting-rod and C the crank, K the crank shaft. G is the crosshead, and *r* the piston-rod working in it. In Fig. 14 the piston is half way through the up stroke. The eccentric *e* on the crank shaft drives the piston valve *p* (Fig. 15) through lever *l*. The exhaust is seen at E; *k* is the small opening about half way up the cylinder, covered by a flap valve; an external flame burns behind it at *n*, and at *o* is a second auxiliary flame to rekindle the other when blown out. Fig. 15 shows the air valve with the holes for regulating the supply, and the action of the piston valve *p*; the gas enters at *i* (Fig. 14).

Deutz Engine.—MM. Otto and Langen had by this time formed their business into a company at Deutz, near Cologne, and the firm was henceforth known as the "Gas-Motoren Fabrik Deutz." They had been working incessantly to improve their engine, but after introducing several modifications, they finally abandoned altogether the idea of a free piston. At the Paris exhibition of 1878 they brought out the celebrated Otto engine, described in Chapter vi., which rapidly superseded their former and all other motors, and created a revolution in the construction of gas engines.

Brayton.—This American gas engine was introduced by Brayton at Philadelphia in 1873. In 1878 Messrs. Simon, of Nottingham, brought out the motor in England. As in the Otto, the charge was compressed, but otherwise this engine differed from all earlier types, and illustrated the principle of ignition at constant pressure, instead of at constant volume. It was a single-acting, two-cycle motor, with an impulse at every revolution. After compression in a separate pump, the gas and air were delivered into the motor cylinder, but they were not admitted cold and then ignited and exploded, according to the usual cycle of operations. A small flame in direct communication with the cylinder was kept constantly alight, and kindled the gases as they passed it. Thus they were gradually ignited, and entering as flame, drove the piston forward, not by the pressure of explosion, but of combustion. The heat was imparted to the gas at constant pressure—that is, the piston moved as soon as the flames began to enter the cylinder, but there was no sudden explosion. A wire gauze was fixed behind the light, to prevent the flame from striking back into the compression cylinder. This method of ignition worked well as long as the wire gauze remained intact, but

it was liable to burn into holes, and if the gases found their way back through any aperture, an explosion followed, and the light was extinguished. On this account Brayton abandoned the use of gas in his engine, and substituted petroleum vapour. A description of this later engine will be found in Chap. xviii.

Simon.—To this gas engine Messrs. Simon added a small boiler above the cylinder, the water in which was evaporated by the heat from the exhaust gases. The engine,* first exhibited at Paris in 1878, was vertical and single-acting. The steam injected into the motor cylinder increased the expansive force of the gases, and helped to lubricate the piston. This idea was not a novelty. It had been tried by Hugon, but neither his engine nor the Simon was practically improved by it. On this point Professor Schöttler pertinently asks—"Whether it can be considered an advantage, since the gas engine is expressly designed to avoid the defects and dangers of a steam boiler, to add the latter to it?"

Fig. 16.—Simon Vertical Engine. 1877.

Fig. 16 gives a section of the engine; a description will explain the method of working. Like the Brayton, it is a two-cycle engine. A is the motor, B the pump cylinder, and K the crank shaft. Gas and air are admitted by the slide valve S_1 at the top of the pump cylinder, and drawn in through the valve *a* at the down stroke of the piston; the up stroke compresses and drives them through another valve *b* into the receiver *c*. From here they pass into the motor cylinder A, through the slide valve S; *j* is a gas jet burning continually in front of a wire gauze, at which the gases are ignited in their passage, and by their expansion drive down the piston P. The exhaust is worked by the slide valve *d* driven from

* Partly founded on Mr. Beechey's design.

the main shaft. The products of combustion are led through the coiled tubes *e* in the small boiler F before discharging into the atmosphere. As soon as some of the water in the boiler is evaporated by the heat of the exhaust gases, the steam passes through the pipe *f* and the slide valve S into the motor cylinder. A small cam *h* on the governor G acts upon the slide valve S_1 for admitting the gas and air, and cuts off the admission entirely as soon as the speed of the engine becomes too great; this is shown in Fig. 16.

Several experiments have been made upon the Brayton and Simon engines. In 1873 Professor Thurston tested a Brayton engine in America, of 5 nominal H.P., and found that the maximum pressure in the cylinder was about 75 lbs. per square inch at the beginning of the stroke, decreasing to 66 lbs. at the cut-off. The indicated H.P. was 8·62, brake power 3·98, and consumption of gas 32 cubic feet per I.H.P. per hour; but the power used for driving the pump caused the effective horse-power to be less than half the indicated. Deducting this, Mr. Clerk calculates the expenditure at 55·2 cubic feet per I.H.P. per hour. Another experiment made by Mr. M'Mutrie, of Boston, showed a maximum pressure in the cylinder of 68 lbs. per square inch, the piston speed was 180 feet per minute, and the total power developed 9 I.H.P., the friction and other resistance amounting to nearly 5 I.H.P. Fig. 17 shows a diagram of this trial. The diagram of a Simon engine at Fig. 18 was taken by Dr. Slaby.

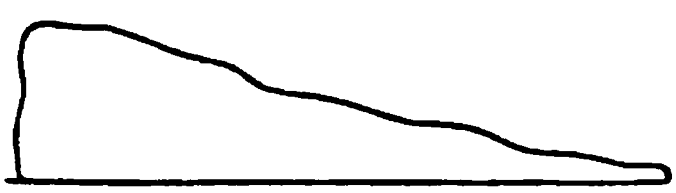


Fig. 17.—Brayton Gas Engine—Indicator Diagram.

Fig. 18.—Simon Engine—Indicator Diagram.

In a history of the development of the gas engine it is important to study not only modern working motors but those engines which, although no longer made, were good in design and principle. During the last twenty-five years many have been brought out, excellent in theory and often in workmanship, which have not permanently succeeded only because they were found to infringe previous patents, or were superseded by more practical types. None of these engines date earlier than 1878. In describing them it will no longer be necessary to distinguish between single-acting and double-acting engines. The double-acting type of motor, in which the charge was introduced alternately at either end of the closed cylinder, was abandoned after the failure of the Hugon, for reasons already given. For many years all gas engines, with the exception of the Griffin and one or two foreign motors, were single-acting,

admitting the charge at one end only of the single cylinder. Since 1900 double-acting engines have again been successfully made.

With the advent of the Otto gas engine a new era began. Until the appearance of this motor in 1876, not one of the many engines produced had utilised the cycle of operations indicated, many years before, as the best and most economical by Beau de Rochas. Neither invention nor practical application were wanting, and as none had proved a real success, we may at least assume that their failure was due partly to the neglect of this cycle. It was Otto's special merit that he was skilful enough to put the principles of the French *savant* into working operation, and the success of his engine proved their value. It has, however, defects which in a few years began to be generally recognised. As in all other gas engines expansion is not complete, and the gases are discharged at a relatively high temperature and pressure. The engine has only one explosion and one motor stroke in four—that is, three strokes out of every four of which the cycle consists are spent in negative, and one in positive work. It is a four-cycle motor, and an impulse is obtained for every two revolutions.

Clerk.—It was to remedy the second defect, the one working stroke in four, that Mr. Clerk applied himself, in the important two-cycle engine he produced and exhibited in 1880. Its special feature was that an explosion at every revolution was obtained. Of the four operations of the cycle Clerk proposed to transfer the first only, admission, to an auxiliary cylinder, called the displacer, into which the gas and air were drawn, slightly compressed, and delivered into the working cylinder. Here they drove out before them the products of combustion. The motor piston in returning compressed this charge into a chamber at the further end of the cylinder. It was then fired and drove the piston forward, the displacer piston taking in a fresh charge of gas and air. The exhaust ports in the front part of the cylinder were uncovered by the piston as it moved out. The discharge of the exhaust gases constitutes another fundamental difference between the Otto and the Clerk engines. Otto considered that the presence of a certain quantity of unburnt gases, by retarding the progress of combustion, contributed to the efficiency of his engine. Clerk held that this residuum of unconsumed gas was highly injurious to the fresh charge, which it diluted and rendered more difficult to ignite. If the motor cylinder were previously cleansed, as far as possible, of the products of combustion, a weaker mixture might be used for the charge, and more perfect ignition and greater economy obtained.

Figs. 19 and 20 give a sectional elevation and plan of the Clerk engine. A is the motor cylinder with piston P, B is the displacer cylinder with piston D, which is set on the crank at an angle of 90° in advance of the motor piston, G is the conical compression space at the

back of cylinder A. There are two automatic lift valves, shown at Fig. 19, H, from which the gas and air pass through the pipe W (Fig. 20) into the displacer cylinder, and F, which is raised to admit the charge under slight pressure into cylinder A. Both the valves are provided

Fig. 19.—Clerk Engine—Sectional Elevation. 1880.

with "quieting pistons," to prevent noise or shock. The ignition slide valve S has a flame *o* which is continually relit from the permanent Bunsen burner at *b*. Near the front of the motor cylinder are the two exhaust ports E_1 and E_2, uncovered by the piston P when it reaches the

Fig. 20.—Clerk Engine—Sectional Plan. 1880.

end of its stroke, and from whence the gases of combustion pass into the discharge pipe E.

The action of the engine is as follows:—The piston D of the displacer moves out, and draws in a charge of gas and air through H. The seat

of this valve is pierced with holes to admit gas from the supply pipe, the forward movement of the displacer piston lifts the valve, the air enters from chamber R below, and mixes thoroughly with the gas penetrating through the holes. The number and size of the holes, in proportion to the lifting area of the valve, regulate the supply of gas, and therefore the richness of the mixture. The air valve H falls back on its seat by its own weight, but the gas supply is cut off before the piston D has quite reached the end of its stroke. The last part, therefore, of the charge in the displacer cylinder, first expelled as the piston begins to return, is pure air. Meanwhile the out stroke of the motor piston has begun, at an angle of 90° behind that of the displacer, and near the end of the stroke the exhaust ports E_1 and E_2 are uncovered. The pressure inside the motor cylinder is immediately reduced to that of the atmosphere. The displacer piston has already nearly completed its return stroke, and the slight pressure exerted on the charge is sufficient to lift the automatic valve F, and to admit the gas and air into the conical chamber G, at the end of the motor cylinder. As the motor piston passes over the exhaust ports, the fresh charge entering from the cool displacer, and immediately expanded by the heat of the motor cylinder, drives out the products of combustion before it. Mr. Clerk admits that a small part of the fresh charge escapes with them, but, owing to the arrangement of the admission valves, this is mostly pure air. The motor piston in returning first covers the exhaust ports, the valve F is instantly closed by a spring, and admission from the pump cylinder cut off. The mixture is then compressed into the chamber G, while the displacer piston begins the out stroke, and takes in a fresh charge.

Fig. 21.—Clerk Engine—Ignition Valve. 1880.

Ignition follows by a flame in the slide valve S. The method adopted, shown in Fig. 20, but more clearly in Fig. 21, differs from that used in engines having only one motor stroke in four, because an ignition is required at every stroke. The small combustion chamber or cavity 1 (Fig. 21) in slide valve S has two openings. On one side it communicates with the Bunsen burner *b* through the port 2, on the other by port 3 with the outer air, or with the explosion port of the cylinder, according to the position of the slide. A small portion of the compressed mixture is admitted from the explosion port 5, through an opening 4, into a grooved hollow in the slide valve, and is carried round to the cavity or

chamber 1, which it enters behind a grating 7. At 8 is shown the pin in the slide regulating the supply of gas to the grating. At the moment when port 2 of the cavity is open to the Bunsen jet burning against the face of the valve, port 3 communicates through 6 with the outer air. The gases ignite gradually as they enter the cavity through the grating, the products of combustion discharging into the atmosphere, and the gases being fed with air through port 6. As the slide moves up, carrying the burning mixture, port 2 is closed and the flame cut off, and port 3 is brought opposite the cylinder explosion port. Explosion follows at the inner dead point, the piston is driven forward, the displacer takes in a fresh charge, and the cycle is repeated. The volume of the two cylinders is so proportioned in this engine as to prevent the escape of any considerable part of the incoming charge with the exhaust gases. The mixture originally admitted is in the proportion of 1 part of gas to 8 of air, but a small part of the products of combustion remains in the cylinder, and mixes with it. The composition of the actual charge is, therefore, 1 of gas to 10 of air and products.

Clerk Governor.—The governor in the Clerk engine is simple. Between the upper and lower lifting valves for admitting the charge to the motor and displacer cylinders is a gridiron slide. While the engine is working under normal conditions, this is kept open during the charging stroke by a spring and lever, worked from the slide valve S; but if the speed becomes too great, the balls of the governor moving out raise a lever, which catches into the lever moving the gridiron valve, and lifts it. The valve is drawn forward and closed, and the admission of gas and air wholly cut off.

For starting, a special apparatus was designed by Mr. Clerk. The pipe through which the gases pass from the displacer to the motor cylinder communicates with a small reservoir, into which a supply of gas and air is forced while the engine is running, and compressed to 60 lbs. per square inch. To start the engine, the crank is brought round to the inner dead point, and communication established between the two cylinders and the reservoir. The compressed air thus admitted drives back the displacer piston to take in a charge, and the motor to uncover the exhaust ports.

Tests and experiments on the Clerk engine have been made by the inventor and the makers. The engines varied from 2 H.P. to 12 H.P., and the number of revolutions from 212 to 132. With the 2 H.P. engine the average pressure in the cylinder was 43·2 lbs. per square inch, and the consumption of gas per I.H.P. per hour 29·8 cubic feet; in the 4 H.P. the average pressure was 63·9 lbs., and the gas consumption 24·19 cubic feet The 8 H.P. engine gave an average pressure of 60·3 lbs. per square inch, and a gas consumption of 20·94 cubic feet; while in the

larger 12 H.P. engine, the diagram of which is shown at Fig. 22, the gas consumption was 20·39 cubic feet, with an average pressure of 64·8 lbs. Glasgow gas was used in these trials. The heat efficiency per B.H.P. varied from 10 per cent. to 13 per cent. (See Table No. 1 at end of book.)

Although good in theory and practice, the Clerk engine did not completely overcome the defect of the Otto and many other gas engines, the want of sufficient expansion. As the exhaust ports opened when the motor piston had passed through three-quarters of its stroke, expansion

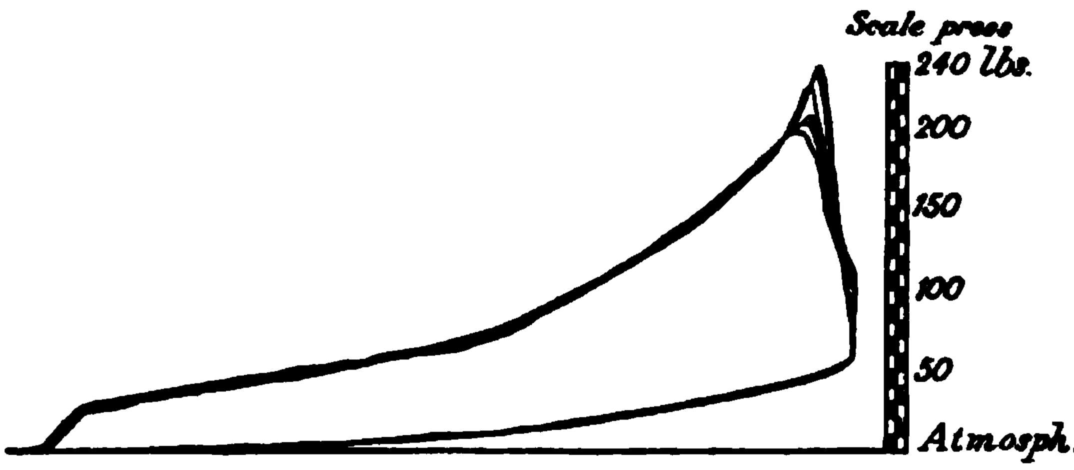


Fig. 22.—Clerk 12 H.P. Indicator Diagram.

was necessarily limited. This was a disadvantage, but the engine, though it has not been made for many years, was more economical in working than previous motors.

Beck Six-Cycle Type.—The Beck engine is the first example of a new cycle of operations. It belongs neither to the original double-acting two-cycle type, giving an explosion every revolution, nor to the four-cycle type of Beau de Rochas, but is known as a six-cycle engine. In other words, there is an explosion every sixth stroke, or the piston makes three forward and three return strokes for three revolutions of the crank. The object of thus lengthening the ordinary sequence of operations is to drive out more completely the products of combustion by introducing, between every explosion and motor stroke, one stroke, forward and return, called a "scavenger charge," during which pure air is drawn in and expelled. Engineers are still divided in opinion respecting the best method of disposing of the products of combustion. By Otto they were purposely retained, in order to diminish the force of the explosion, and he and others thought that there was an advantage in diluting the incoming charge with the burnt gases. Others are so strongly convinced of the injurious effect of leaving behind any portion of the products of combustion that they sacrifice a complete stroke to get rid of them, and maintain that, the cylinder being thoroughly cleansed, the incoming charge is so pure that a much weaker mixture may be employed. With only one explosion every six strokes, there is, of course, great difficulty in regulating the speed of the engine, and the cooling action on the cylinder walls of the charge of fresh air is also considerable. For these reasons the six-

cycle type has found little favour, and is now seldom seen. It is best adapted to double-acting engines, adjusted to give an explosion every three strokes, first at one, then at the other side of the piston.

The Beck engine was of the original six-cycle type, single-acting, single-cylinder, and gave one explosion per six strokes. The working cycle of operations was as follows:—

Revs. of Crank.				
1	First stroke, forward.	Admission of charge.	Negative strokes absorbing power.	Three revolutions per explosion (one cylinder).
	Second stroke, return.	Compression of charge.		
2	Third stroke, forward.	Ignition, explosion, expansion.	Positive (*motor*) strokes giving power.	
	Fourth stroke, return.	Discharge and exhaust.	Negative strokes absorbing power.	
3	Fifth stroke, forward.	Admission of pure air.		
	Sixth Stroke, return.	Discharge of air to atmosphere.		

Except with regard to the scavenger charge of pure air, the engine resembled the Otto. Admission and ignition were effected by a slide valve adjusted to make one-third as many strokes as the motor piston.

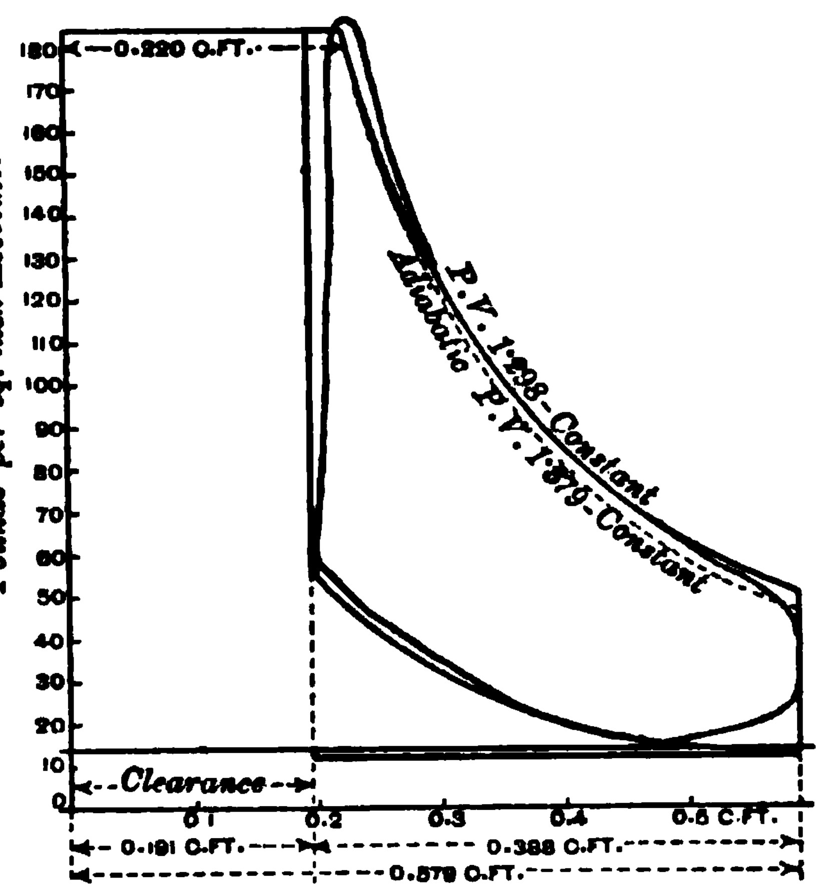


Fig. 23.—Beck Engine—Indicator Diagram. 1888.

The compression space was separated from the water jacket by a cylindrical layer of non-conducting materials, and the mixture was thus ignited in a chamber kept continually at a high temperature. By introducing the scavenger charge of pure air, and by adjusting the admission valves, the richest mixture entered the cylinder first, and the poorest was retained round the ignition port. An electrical governor was used, and the intensity of the current was made to vary with the speed of the engine, the admission of gas being either throttled or wholly cut off.

Beck Trials.—A series of very careful experiments upon a 4 H.P. nominal Beck engine were made in London by Sir A. Kennedy, F.R.S., in 1888. The indicated and brake power, speed, consumption of gas, and jacket water were all carefully observed in six successive trials. Two of these were made at full power and at full speed, at 206 and 212 revolu-

tions per minute, the next two at a mean speed of 166 revolutions, the fifth at 180 revolutions, and the sixth with the engine running empty. The highest power developed was 8 I.H.P., with 6·3 B.H.P., and the maximum pressure during the working stroke was 74·6 lbs. The B.H.P. varied from 6·31, with 206·5 revolutions, to 4·84, with 169 revolutions. The average consumption of gas was 21·42 cubic feet per I.H.P., and 26·79 cubic feet per B.H.P. per hour. The calorific value of the gas used was 611 thermal units per cubic foot. An indicator diagram of this trial is given at Fig. 23.

Wittig & Hees.—This vertical engine was made for some time in Germany, and tested by Professor Schöttler in 1881. It was a two-cycle engine, of the same type as the Clerk, with pump and motor cylinders, between which the Beau de Rochas cycle of operations was divided. Ignition was by an external flame in the slide cover, which communicated with the charge in the cylinder through a port in the slide valve.

Compression.—In the engines hitherto described, expansion of the charge during one forward stroke, or part of a stroke, was only in the same ratio as the other operations. Of the two great improvements on the original type, compression and expansion, the first, compression of the gas and air after admission, already formed a part of almost every cycle, but expansion was still imperfect. Even now, inventors have not succeeded in increasing it so as to utilise to the utmost the high pressures and temperatures obtained. Various schemes have been proposed, and methods suggested to remedy this defect, which, with its correlative loss of heat, still remains one of the difficulties of gas and oil engines. Two attempts to solve the problem were made in the Seraine and the Sturgeon engines; drawings of both will be found in Schöttler's book (2nd edition).

Martini.—This engine, patented in 1883, and shown at the Paris Exhibition of 1889, presents an interesting development of the idea of increased expansion. It is a four-cycle motor, in which admission and compression are effected during one revolution with a shorter stroke, and expansion and exhaust during the next with a longer stroke. A larger circle is described by the crank during expansion and exhaust, and a smaller circle during admission and compression, and the length of either stroke can be modified. Thus the piston approaches the explosion end of the cylinder more nearly during compression than during exhaust. Drawings of this curious engine, which bears much resemblance to the Atkinson "Cycle" motor, are given in M. Richard's* book.

Tangye.—A compact and handy horizontal two-cycle motor, resembling the Clerk in certain respects, was formerly constructed by

* *Les Moteurs à Gaz.* Par G. Richard, Paris.

Messrs. Tangye of Birmingham. There was one cylinder closed at both ends, and the piston-rod worked through a stuffing-box. Explosion took place at the back end of the cylinder, furthest from the crank, and with the help of an auxiliary chamber, an impulse every revolution was obtained. At the crank end the charge was admitted at atmospheric, and passed on at slightly increased pressure into an auxiliary chamber, from which it was drawn in at the other end of the cylinder, compressed, ignited, and expanded. The openings for the exhaust were at the crank end. Thus on the crank face of the piston the return stroke admitted the mixture of gas and air, and the forward (expansion) stroke compressed it into the auxiliary chamber. At the end of this stroke the piston overran the exhaust ports, reduced the pressure in the cylinder below atmosphere, and communication between it and the receiver was established. A fresh charge entered, drove out the products of combustion, was compressed by the return stroke, and ignition at the dead point followed. Thus one revolution completed the whole working cycle, and by storing up the pressure in an intermediate receiver, and utilising both faces of the piston, one explosion per revolution was obtained. A drawing of this ingenious little engine is given by Clerk.* The makers have now adopted the usual Otto type, as described in the modern section.

Various.—Several small gas motors, including the Economic, Bénier and Lamart, and the Forest, were brought out abroad about twenty years ago, though they do not appear to have found their way into England. In all of them the charge was introduced at atmospheric pressure. It was difficult at that time, without infringing the Otto patent, to produce single cylinder engines using compression. For small powers, therefore, compression and the resulting economy not being of so much importance as simplicity, the easier method of firing the charge without previous compression was preferred. As the temperature in the cylinder was thus reduced, a water jacket could be dispensed with, and the cylinders were ribbed externally to afford a larger cooling surface to the air.

Drawings of the Forest engine are given by Schöttler and Witz, and of the Economic by Witz.† A description of the Bénier air engine will be found in Part III., and of his gas engine at p. 152. The Noel and the Durand, both made only for small powers, also achieved a certain measure of success in France, and were exhibited at Paris in 1889. The Durand was adapted for working either with gas or carburetted air, and the inventor gave much study to the subject.

* Clerk, *The Gas Engine*, p. 196, 3rd Edition.

† *Traité Théorique et Pratique des Moteurs à Gaz.*, vol. i. Par Aimé Witz, Paris.

Baldwin.—This was an interesting engine of the Clerk type, introduced from America in 1883. It had one horizontal cylinder divided into two parts, the back forming the motor end, and the front the pump. Ignition was effected electrically from a small dynamo driven from the main shaft. Three different methods were employed to regulate the speed, first, by diminishing the volume of the mixture, secondly, by partial, and thirdly, by total suppression of the gas, according to the greater or less excess of speed. A drawing of the engine is given by Witz, vol. i., p. 254.

A short description of many other small gas engines, now only of historical interest, will be found in the first and second editions of this book, to which readers desirous of studying the subject are referred.

CHAPTER V.

THE ATKINSON, GRIFFIN, AND STOCKPORT ENGINES.

CONTENTS.—Principle of Atkinson Engines—Differential Engine—Cycle Engine—Trials—Griffin Gas Engine—Trials—Stockport Engine, Earlier Type.

THE ingenious mechanism of the Otto engine described in Chapter vi., and the fact that it was the first to realise the cycle of Beau de Rochas, has made it so popular that practically hardly any other type of engine is now constructed. But that it has defects its warmest supporters will admit. The question often arises whether, with a different cycle, a lower gas consumption and better design are not possible. Experiments prove that not more than one-fourth of the heat given to the best Otto engine is utilised as power.* Defective expansion is one of the chief causes of this loss of heat, and how to remedy it is the problem still occupying the minds of engineers. To increase the length of the piston-stroke enlarges the cylinder volume, and admits more of the charge, and at the same time allows greater scope for the expansion of the gases. It is the proportion of the volume of admission to the total volume, or number of expansions, which may be altered, and the piston made to travel through a shorter distance when admitting and compressing, than when expanding the charge. The solution of the problem presented by Mr. Atkinson some years ago was original and ingenious.

Principle of Atkinson Engines.—This inventor introduced two engines, the main principle in which was the same, although carried out in different ways. The whole cycle was performed in one cylinder; there was one motor-stroke in four, and this stroke corresponded to one revolution of the crank only. The four operations of the Beau de Rochas cycle —admission, compression, explosion plus expansion, and exhaust—were effected in four separate strokes of different lengths. Hence the compression or clearance space varied according to the operations taking place in the cylinder, whether the piston was admitting, compressing, or expanding the charge. Like others who have studied the subject, Mr. Atkinson considered that the two main sources of waste of heat were the exhaust and the water jacket, and he attempted to reduce these losses by ar-

† The heat efficiency of the best Otto-cycle gas engines is now [1905] from 28 to 30 per cent. See Table of Tests.

ranging the connection between the piston and the crank, so as to give different lengths of stroke. If the piston travels more quickly, there is less time for the heat to be carried off by the jacket; if a longer expansion stroke is obtained, the heat and pressure of the gases have more time to act in doing useful work on the piston, before the exhaust opens. The more rapid and longer expansion obtained by Atkinson, after many trials, formed the chief novelty in his engines. He claimed to expand the charge to the original volume during one-eighth of a revolution, as compared

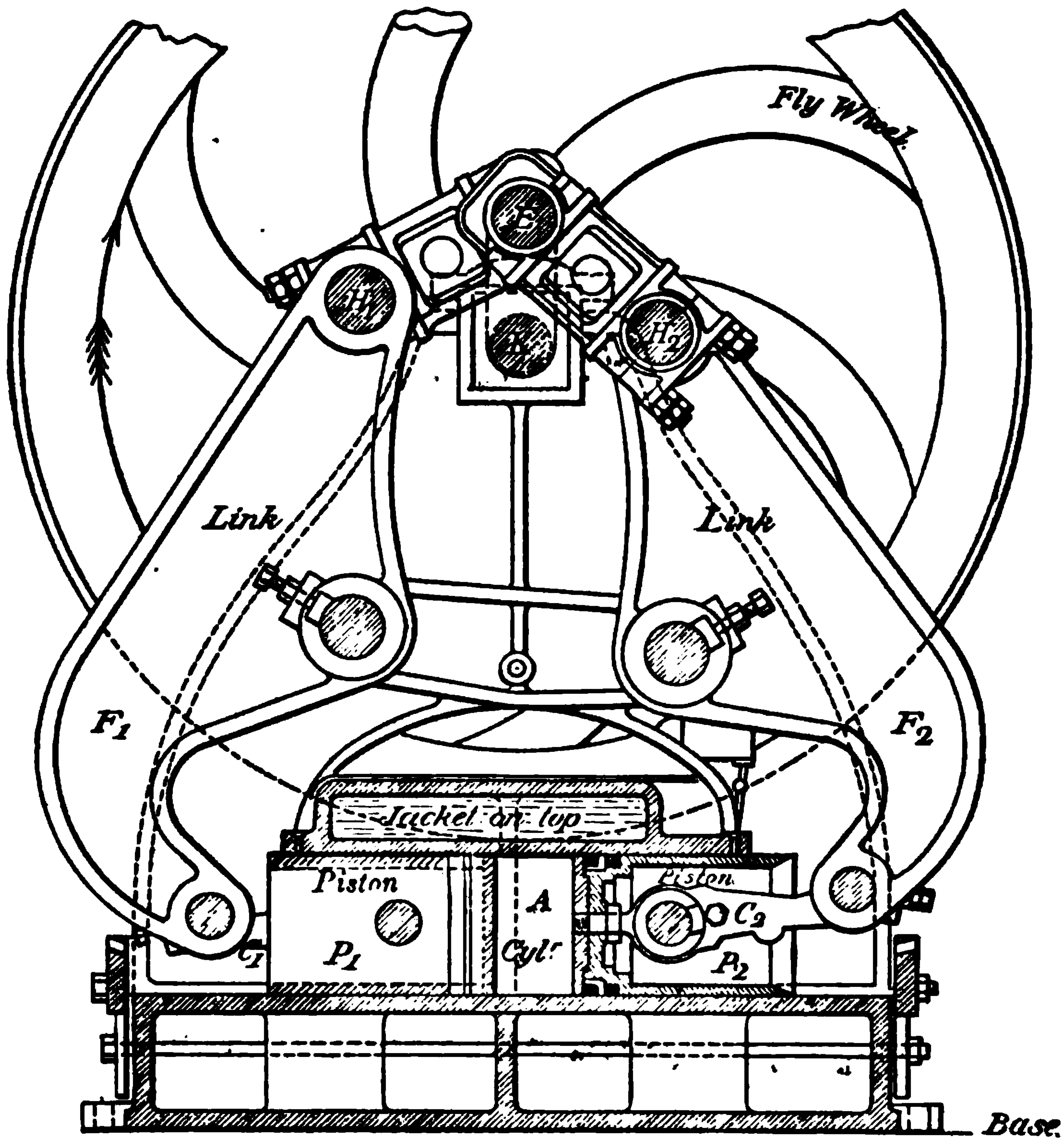


Fig. 24.—Atkinson Differential Engine. 1884.

with half a revolution during which it is expanded in the Otto. In the latter engine the charge is drawn in during one out stroke of the piston, or half a revolution, and expanded during the next, while the crank makes another half revolution, to the original volume—namely, the total volume of the cylinder. In the Atkinson engine, the stroke expanding the charge was nearly double as long as that admitting it, and hence the charge expanded to almost twice its original volume. In a 6 H.P. motor the suction or admission stroke was about 6½ inches, the expansion stroke

about 11½ inches. As the whole cycle was carried out during one revolution of the crank, this increased expansion was obtained in one-quarter revolution, and expansion to the original volume in one-eighth revolution, or one-quarter the time occupied in the Otto engine. The heat transmitted through the walls to the jacket should be in proportion—first, to the time the wall surfaces are exposed, and secondly, to the differences of temperature between them and the gases they enclose. Rapid and prolonged expansion ought, therefore, to check the waste in both directions. The quick moving out of the piston brings the ignited charge in contact with the walls for a much shorter time, and, the heat being absorbed in expansion, by the time the exhaust opens the gases are comparatively cool.

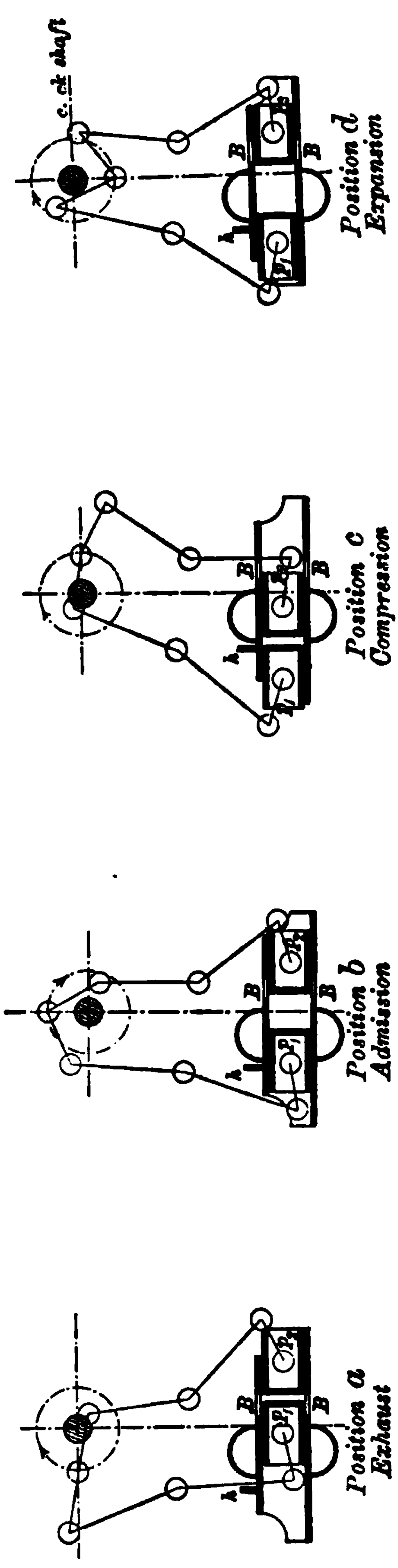


Fig. 25.—Atkinson Differential Engine—Piston and Links, Positions. 1884.

Differential Engine.—As early as 1879 Mr. Atkinson took out a patent for a compression engine of the Otto type, in which ignition was obtained by a red-hot tube. This was one of the first instances of a working engine firing the gas in this way; the same method was employed in the same year by Leo Funck. Atkinson soon abandoned this type of construction, and began to work on new lines. Fig. 24 gives a sectional elevation of his first or Differential engine, shown at the Inventions Exhibition in 1885. The horizontal motor cylinder A contains two pistons, both working outwards, and joined by their connecting-rods C_1 and C_2 to the bent levers F_1 and F_2 which act through H_1 H_2 upon the crank shaft K. Of these two pistons the left-hand one, P_1, may be called the pump piston, and chiefly compresses the charge; the right hand one, P_2, is the working piston, and effects the greater part of the working-stroke, but both pistons co-operate in

utilising the explosive force of the gases. There is only one cylinder, open at both ends; during the compression of the charge the pistons hold the exhaust port and the ignition tube closed. Air is admitted through an automatic lift valve, gas through a valve opened by a rod from an eccentric on the main shaft. The rod terminates in a knife-edge acting on the lever of the gas valve, and if the speed be too great the governor, which is driven by a pulley from the crank shaft, shifts the valve-rod out of position, and no gas is admitted. Ignition is by a hot tube without a timing valve. The exhaust, uncovered by piston P_2 in its out stroke, is closed by an automatic valve.

The method by which the two pistons act upon the crank is given in the four positions at Fig. 25, showing the links, the levers, the movement of the connecting-rods, and the variable clearance space. p_1 and p_2 are the pump and working pistons, and *h* the ignition tube. In the first position, *a*, the two pistons are shown close together, and both at one end of the cylinder. The products of combustion have been completely expelled, the clearance space between the pistons is reduced to its smallest limits. The energy of motion in the flywheel now lifts the crank, the pump piston p_1 moves rapidly to the left, the other piston following it slowly, the automatic admission valves are uncovered at B, and the charge (position *b*) enters between the two pistons, through the openings. In position *c* the admission valves are closed, the working piston has followed the pump piston rapidly to the further end of the cylinder, and the charge is shut into the diminished volume between them. A slight further movement of the pump piston uncovers the ignition tube, the compressed gases enter, the charge is fired, and the working piston moves rapidly out to the extreme limit of the cylinder, uncovering the exhaust valve. The pump piston follows more slowly, driving out the products of combustion (position *d*). The ratio of admission and compression to expansion and exhaust is as 2·58 to 4·44.

In theory the action of the Differential engine appears to realise almost complete expansion, but the practical results obtained were not satisfactory. Professor Schöttler found that the consumption when running empty was very high, and the mechanism of transmission was also defective. The levers, links, and connecting-rods were rather unwieldy, and after a few years Atkinson improved upon the engine by the production of the "Cycle" (1886) in which the same principle was retained, embodied in a much simpler form.

"Cycle" Engine.—In outward appearance this engine seemed to differ little from the ordinary type of a compression gas engine. Nevertheless, in it, as in the Differential, the expansion and exhaust strokes were longer than the admission and compression, and the whole cycle of operations was completed during one revolution of the crank, with one

piston and cylinder, without the aid of a pump. This constituted the novelty of the "Cycle" engine. Instead of using two pistons, the four unequal strokes were all obtained with one piston, working upon the

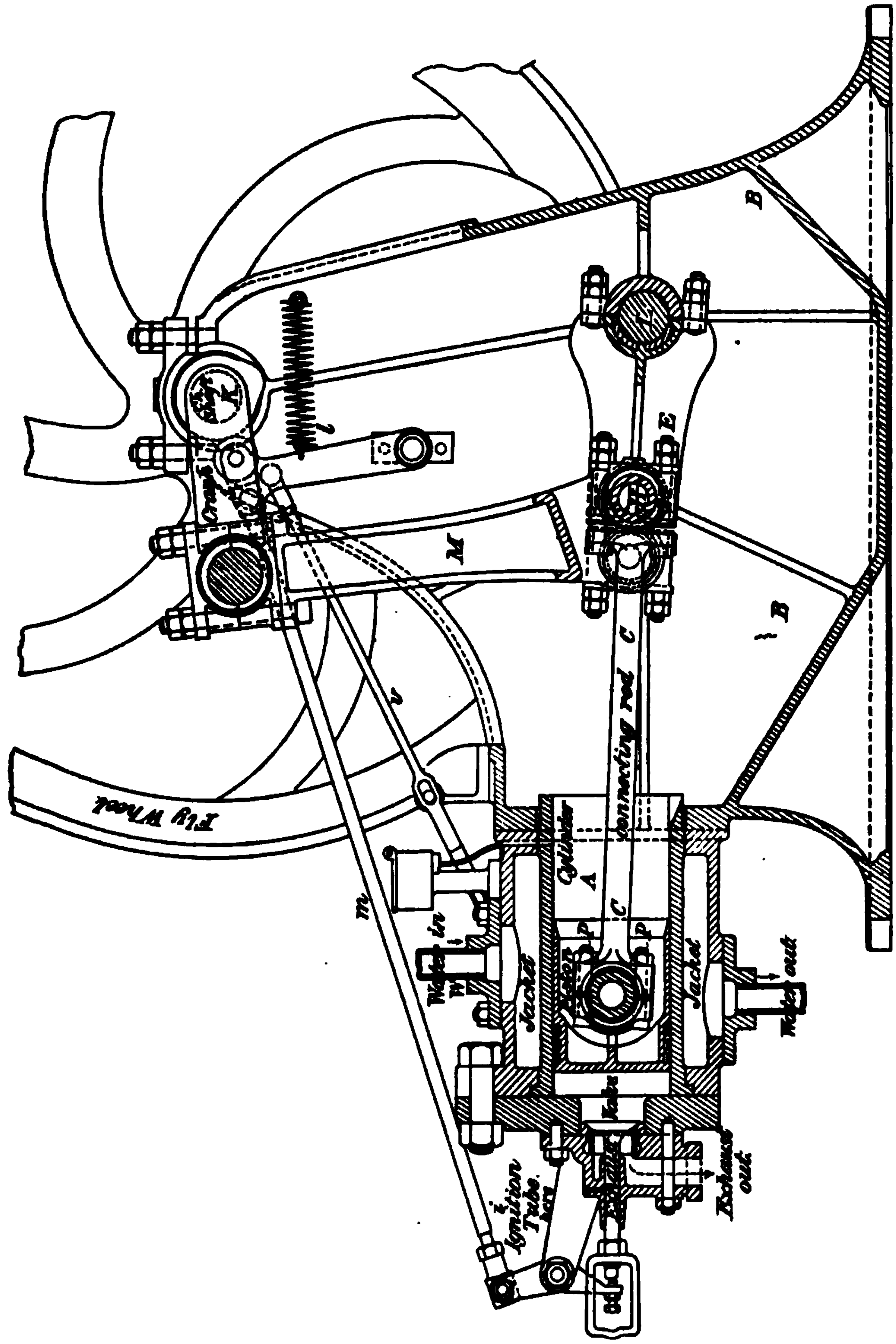


Fig. 26.—Atkinson Cycle Engine—Elevation. 1886.

motor crank through a series of rods, links, and levers. The admission and exhaust were operated with valves in the ordinary way. There was no valve to the ignition tube, but the charge was ignited automatically during the compression stroke.

Fig. 26 gives a sectional elevation of a "Cycle" engine. A is the

cylinder, P the piston, at W the water enters the jacket. The cylinder is placed upon a strong base-plate B, in the interior of which is the mechanism for transmitting power to the crank. E is the lever, H the small crank or vibrating link, the end of which only is seen, C is the connecting-rod, M the lever joining H to the crank shaft K, and L the fixed point in the base, about which the lever E and the small crank H oscillate. The ball governor acts upon the gas admission valve by a lever and rod. As long as the speed is regular, the valve opens to admit the gas. The valve-rod *v* rests against it, but is not solidly connected, and if the speed be increased it is drawn back, the valve remains closed, and no gas is admitted. The valves for admitting and discharging the gases are worked by two rods, one of which is shown at *m*, and opened by two cams on either side of the crank shaft. The ignition tube *i* is permanently open to the cylinder, and has no timing valve. The ignition of the charge was based upon the theory that a small quantity of the gases of combustion always remained in this narrow passage. The pressure of the return stroke drove these gases and a portion of the fresh compressed mixture up the red-hot part of the tube, where they ignited, and spreading back into the cylinder fired the remainder.

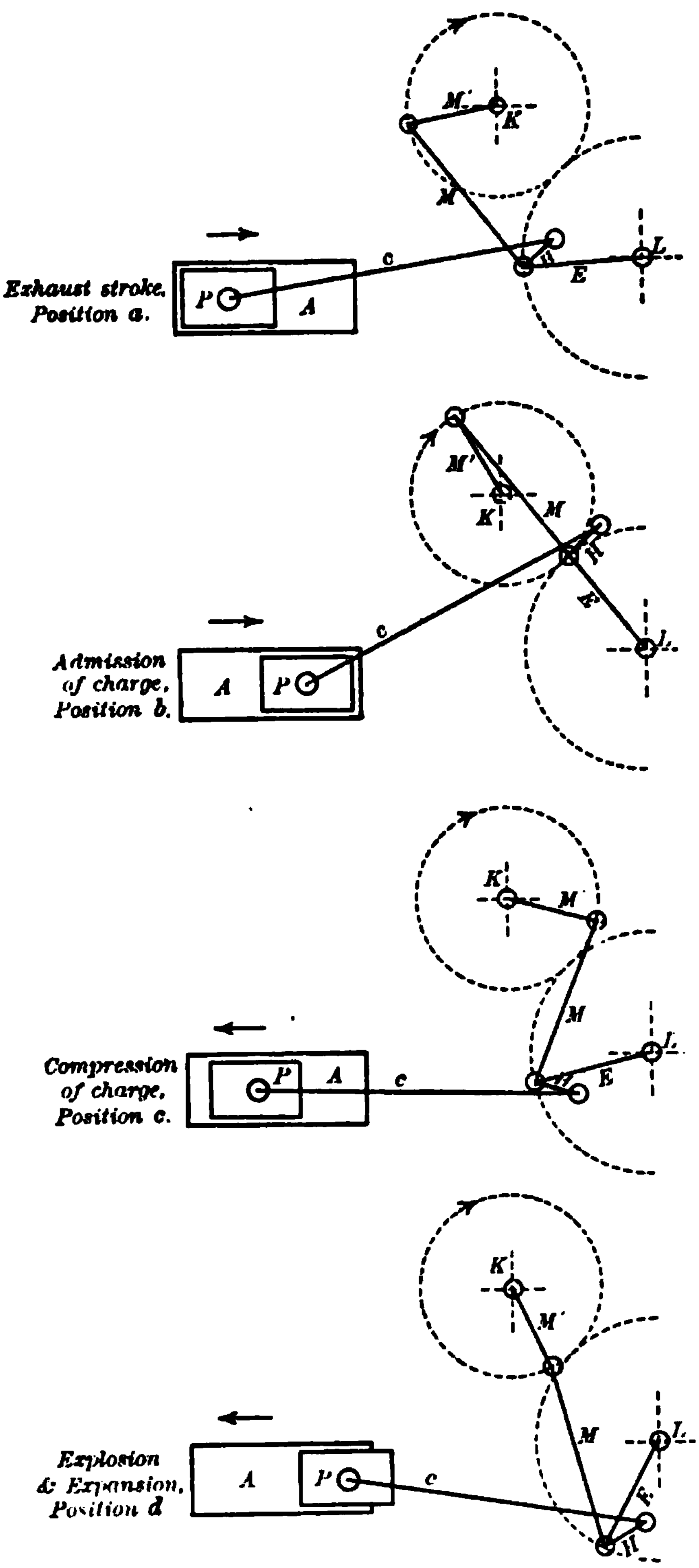


Fig. 27.—Atkinson Cycle Engine—Four positions of Link and Toggle Motion. 1886.

The method worked well, owing probably to the purity of the charge obtained by the long exhaust stroke, and the moment of firing was determined by raising or lowering the chimney, and altering the position of the tube.

The distinguishing feature of the Atkinson engine was the link and

toggle motion shown in four positions at Fig. 27. A is the cylinder and P the piston. c is the connecting-rod to the small vibrating link H, which, through E, is joined to the fixed point L. M is the lever connecting through the crank M_1 to the crank shaft K. The relative positions of these parts during the four successive strokes of the cycle are shown in the drawings. The ratio of the cylinder volume utilised for compression was 2·5, and for expansion 4·3.

The proportion of expansion to admission and compression could be varied to suit any kind of gas, by adjusting the centre L and link H. The prolonged exhaust stroke was a source of economy. The gases were discharged at a pressure of only 10 lbs., and the cylinder being thoroughly cleansed after each explosion, ignition was said to be more certain.

Trials.—Trials on the Atkinson engine are given in the table at the end of the book. It was often tested, among others, by Professors Unwin, Schöttler, and Thurston. In an experiment made in 1887, the consumption of London gas was 22·5 cubic feet per B.H.P. per hour, and

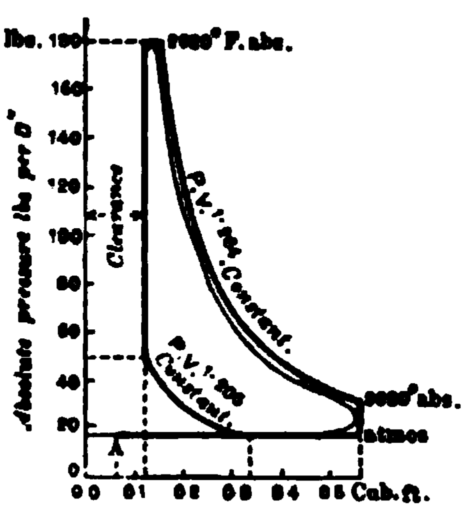


Fig. 28.—Atkinson Cycle Engine —Indicator Diagram. *Society Arts.* 1888.

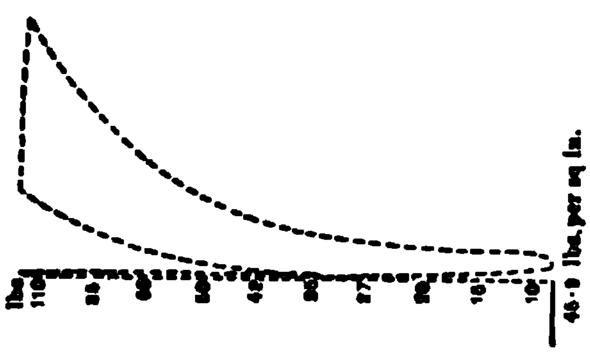


Fig. 29.—Atkinson Cycle Engine —Indicator Diagram. 1891.

the ratio of expansion 3¾, as compared with 2½ in the Otto. The Society of Arts' experiments are mentioned at p. 94. In these the consumption of gas for the Atkinson engine was 19·22 cubic feet per I.H.P. per hour, the lowest figure recorded for any of the competing engines. A diagram of this trial is given at Fig. 28. A very complete test was made in October, 1891, by Mr. Tomlinson, in which the efficiency of the engine and the value of the Dowson gas used to drive it were determined. The engine indicated 21·95 H.P., and the consumption of anthracite was 1·06 lbs. per I.H.P. per hour. Fig. 29 shows a diagram taken at this trial.

This ingenious engine is no longer made, and Mr. Atkinson is now with the firm of Messrs. Crossley Bros.

The Griffin Gas Engine.—This horizontal engine, constructed by Messrs. Dick, Kerr & Co., has had some success in England, in cases where steadiness and regularity of speed are required for electric lighting.

It belonged originally to the six-cycle type, was in a certain sense double-acting, and both sides of the piston were used for expansion of the charge.

At page 57 will be found a description of the method of operations in a six-cycle engine. There are six strokes, comprising—1, Admission of charge; 2, compression; 3, explosion and expansion; 4, expelling products of combustion; 5, drawing in air or scavenger charge; 6, expulsion of charge of air. The defects of this cycle are—the want of regularity in the speed, and the loss of power due to the small number of ignitions, there being only one motor stroke in six. These disadvantages were to a certain extent avoided in the Griffin, by making it double-acting, and it virtually became what may be called a three-cycle engine. Instead of one ignition and one working impulse every three revolutions, a charge of pure air was admitted and an ignition obtained, alternately on either face of the piston, at every one and a half revolution of the crank, and for every three strokes. Thus the action was much more regular, but the heat generated by the explosions taking place on both sides of the piston was almost as great as in the Lenoir engine. This was partly counteracted by the scavenger charge of air which, by cooling the cylinder, had a beneficial effect on the temperature of the walls. To diminish further the heat of the explosion, there was not only a water jacket to the cylinder barrel, but to the cylinder cover next the crank, through which the piston-rod worked. This had a cooling effect on the rod, and the indicator diagrams, taken during the trials of the Society of Arts, showed that the mean pressure in the front end of the cylinder was from 6 to 14 lbs. lower than at the back, where there was no cover jacket. In the twin-cylinder engine used for electric lighting, where great regularity in working is required, there were two horizontal cylinders side by side, each single-acting, and having one motor stroke in six. In the one cylinder the cycle was three strokes in advance of the other. The forward motor stroke of one piston corresponded with the expulsion of the scavenger charge of air in the other, and admission in one cylinder with exhaust in the other.

Fig. 30 gives a side elevation, and Fig. 31 a plan of the engine. Power is transmitted by the connecting-rod to the crank shaft K. The counter shaft R is driven from the crank shaft by worm gearing D, in the proportion of 3 to 1. It revolves, therefore, once for every three revolutions of the crank shaft. The cylinder itself, closed at both ends, stands on a base B, through which the air is drawn for the motor and scavenger charges. The slide valves S S_1, driven by eccentrics from the counter shaft, contain the distributing and ignition ports; the two exhaust valves E E_1 worked by cams $c\,c_1$, and levers, are on the opposite side of the cylinder to the slide valves. In Fig. 31 the gas is admitted through two valves, d and d_1, controlled by the graduated cock n, the

air enters at $a\,a_1$, Fig. 30, from B, and the two mingle at the admission valves $m\,m_1$. These valves are opened by cams on the counter shaft

Fig. 30.—Griffin Six-Cycle Engine—Side Elevation.

Fig. 31.—Griffin Six-Cycle Double-Acting Engine—Plan. 1886.

twice in one revolution, or every one and a half revolution of the crank shaft; the gas valves $d\,d_1$ open only once every revolution, or once for

every three revolutions of the crank shaft. Consequently every other time the valves $m\,m_1$ open, they admit only pure air to form the scavenger charge, and every other time they admit air mixed with gas from the valves $d\,d_1$, to form the explosive charge. The gas admission valves are controlled by the governor G, by means of a cam with steps of varying width; the quantity of gas admitted is first diminished, then totally cut off, on one or both sides of the piston, according to the excess of speed.

The charge of gas and air being thus admitted at either end of the cylinder, the slide valves $S\,S_1$ worked by the eccentrics $r\,r_1$ are alternately raised once in every revolution of the counter shaft, and the fresh mixture is made to communicate through the passages shown in Fig. 30 with the permanent burners $b\,b_1$. The charge is thus fired, and the mixture explodes, driving the piston forward. The exhaust valves at $E\,E_1$, Fig. 31, are worked as in the Otto, by cams $c\,c_1$ and levers passing beneath the cylinder. These cams on the counter shaft R open the exhaust first at one end, then at the other of the cylinder, every half revolution of the counter shaft. $T\,T_1$ are the oil cups lubricating the cylinder.

Three trials were made upon the engine, the first by Professor Jamieson, the second by Professor Kennedy, both at Kilmarnock, the third at the Society of Arts' trial competitions in 1888. In Professor Kennedy's trial an engine was tested of 14·2 B.H.P., with 23·6 cubic feet of gas consumed per B.H.P. hour. At the trials of the Society of Arts (diagram Fig 32), the engine indicated 15·47 H.P., and the consumption of gas was 28 cubic feet per B.H.P. hour; the London gas used was poorer than the Scotch.

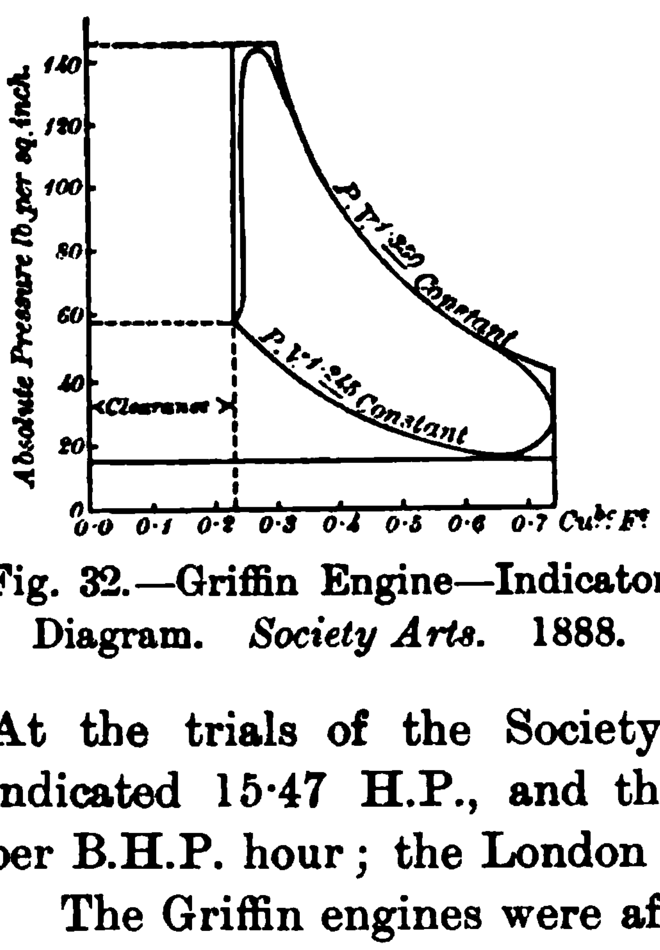
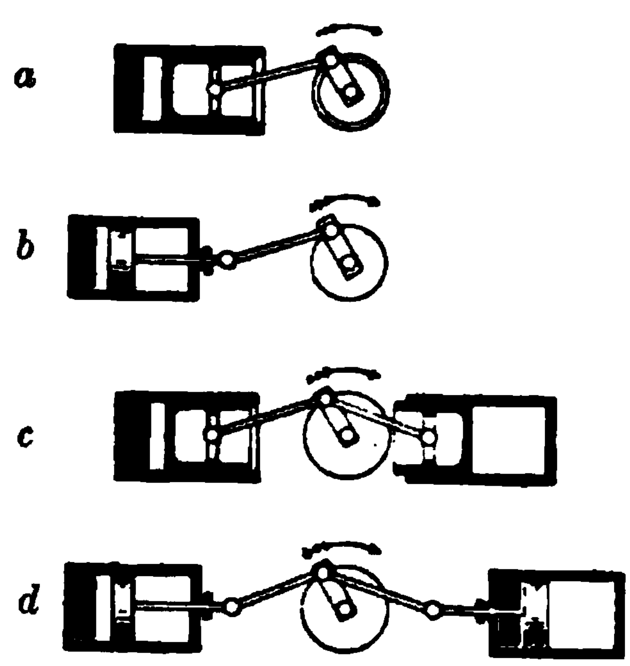


Fig. 32.—Griffin Engine—Indicator Diagram. *Society Arts.* 1888.

The Griffin engines were afterwards worked with the Otto cycle, the scavenger charge of air being omitted. For all powers above 12 H.P. they were constructed double-acting, with explosion of the charge and motor stroke on each side of the piston. The following table shows the working method:—

Front of Piston (Crank end).		Back of Piston.
1. Forward stroke—Admission of charge. 2. Back stroke—Compression of charge.	One revolution.	1. Back stroke—Exhaust. 2. Forward stroke—Admission of charge.
3. Forward stroke—*Explosion* and expansion. 4. Back stroke—Exhaust.	One revolution.	3. Back stroke—Compression of charge. 4. Forward stroke—*Explosion* and expansion.

Lift valves were used, worked from the valve shaft, and performing a double set of functions at either end of the closed cylinder. Motors intended to drive dynamos were fitted with an especially sensitive governor worked by bevel wheels from the valve shaft, which acted by controlling, but not by cutting off, the supply of gas until the load was reduced to one-third. The former arrangement of a cam with steps was discarded in some of the larger sizes, but retained in the smaller. In the double-acting engines the governor usually cut out the ignitions on one side of the piston, while the cycle was carried out as before on the other. In a later type of two-cylinder engines there was an explosion and a motor impulse at each stroke, the charge being ignited and expanded in each cylinder alternately at either end, while it was admitted, compressed, and discharged in the other. The following diagram explains the working action of the Griffin, as compared with the Otto engine :—



(*a*) Otto—1 explosion—2 revs.—one cylinder, single-acting, open end.

(*b*) Griffin—1 explosion—1 rev.—one cylinder, double-acting, closed ends.

(*c*) Otto—1 explosion—1 rev.—two cylinders, single-acting, open ends.

(*d*) Griffin—2 explosions—1 rev.—two cylinders, double-acting, closed ends.

Fig. 33.—Diagram of Single- and Double-Cylinder Explosion Engines.

Note.—Dark mark represents explosion, 1 circle 1 rev., 2 circles 2 revs. All with four-cycle—1 stroke taking in charge, 1 stroke compressing, 1 stroke exploding, and 1 stroke exhausting.

For large powers, the Griffin engines were usually driven with Dowson or other generator gas. In a large tandem engine there were three cylinders, side by side, the two outer high-pressure, the inner low-pressure. One of the high-pressure cylinders exhausted into the latter, the other into the atmosphere. The engine indicated over 600 H.P. with generator gas, and ran at 120 revolutions per minute.

Griffin engines were installed in the electric light station at Belfast, but were latterly used as a reserve. They were started by the dynamos, and the speed regulated by the governor acting on cams divided into layers, thus varying the time during which the gas was admitted to the cylinders, and the strength of the explosion, but not cutting out any ignitions. The plant consisted of six engines—four with two cylinders, and two single-cylinder, all double-acting. The larger engines indicated

up to 120 H.P., and generated 77 electrical H.P. Trials made on it showed a consumption of 18·2 cubic feet of lighting gas per I.H.P., and 23·9 cubic feet per electrical H.P. per hour, during a continuous run of six hours, the engines indicating 111 H.P. at a speed of 161 revolutions per minute. The diameters of the tandem cylinders were 13½ inches and 13¾ inches respectively; stroke 20 inches.

Stockport.—The Stockport engine, made by Messrs. Andrew & Co., and introduced in 1883, was originally a two-cycle single-acting motor, in which compression took place in an auxiliary pump, and an explosion every revolution was obtained. This division of the cycle of operations between two cylinders added to the size and cost of an engine, but increased its steadiness in running. In this respect the motor resembled the Clerk. About 2,000 have been made.

The two horizontal cylinders, motor and pump, were placed opposite each other on the same axis, upon a base through which the compressed charge was conveyed from one to the other. Each had a trunk piston with the crank shaft placed between them. The motor carried two slide valves, a vertical valve for admitting the charge, driven from an eccentric on the crank shaft, and a horizontal slide valve, carrying the ignition flame in a hollow cavity; the latter was afterwards superseded by hot-tube ignition. The two pistons moved alternately in and out, the forward stroke of the pump drawing the charge through the admission slide valve, while the corresponding back stroke of the motor piston uncovered the exhaust port, and drove out the products of combustion. The following back stroke of the pump, corresponding with the forward expansion stroke of the motor, compressed the charge through the same slide valve into a hollow chamber in the base-plate. The pressure then opened a valve into the working cylinder, and the exhaust port being uncovered, the incoming charge helped to drive out the products of combustion. The return stroke of the motor piston closed the exhaust port, ignition followed, and the cycle recommenced.

The hot-tube ignition was a novel feature of this engine. At first these tubes were always made of cast iron, and lasted only about thirty hours. Under ordinary conditions, they are rapidly burnt out by the great heat to which they are subjected, and the quick variations of temperature produce great changes and deterioration in the metal. The fresh compressed charge entering the tube at each stroke is always at a high temperature, while the residuum of exhaust gases left in it during the out stroke is relatively cooler, and owing to these alternations of heat the tube speedily burns away. In the Atkinson and other engines a high chimney was placed round the tube to protect it from draught, and some makers use porcelain tubes. Messrs. Andrew introduced a special composition, made of an alloy of silver, &c., which is said to last for

several months, and not to fuse or cake. Ignition tubes have the advantage of being easily removed and changed when worn out, and are almost universally used in England. They are simple and regular in action, but their temperature is not so high as that of the electric spark, and ignition is perhaps more difficult. For this and other reasons, the charge is generally fired by electricity on the Continent.

In the second double-acting type there were two motor cylinders and two pumps, all horizontal. The motor pistons worked on to the single crank placed between them, while the pumps actuated a second smaller crank on the main shaft, revolving slightly in advance of the main crank. An impulse was obtained at every half revolution, and the engine ran with great steadiness. The third type, with one cylinder and one differential piston, was vertical. The lower side, on which the charge was expanded and discharged, was smaller in diameter than the upper, on which it was admitted and compressed. Thus, the piston virtually divided the cylinder into two parts of unequal area, in which two different sets of operations took place simultaneously.

CHAPTER VI.

THE OTTO GAS ENGINE, 1876.

CONTENTS.—Original Type—Slide Valve—Exhaust—Ignition Hot Tube—Deutz Otto—Crossley-Otto—Scavenging Engine—Trials—Lanchester Self-Starter.

IT is to Otto, the celebrated German engineer, that the honour belongs of having first produced a practical working gas engine using compression, and giving an economical cycle of operations. The Otto engine was brought out at a time when, in the competition between gas and steam, the balance inclined so much in favour of the latter, that it even seemed possible that gas engines would be driven altogether from the field. The construction of the Lenoir and Hugon engines had been more or less relinquished, on account of the quantity of gas they consumed. Of all their successive imitators, none supplied the long-felt want of an engine working as steadily and economically as steam, always ready for work, where a steam engine could not be used. The Otto and Langen engine, which followed the Lenoir and Hugon, was never popular, owing to its unsteadiness, noise, and irregularity. The inventors were fully cognisant of these defects, and for years they laboured to remedy them, working on the principle of admitting the gas and air at atmospheric pressure. At length, however, to the surprise of the engineering world, they gave up altogether this method of construction, and patented in 1876 an engine, shown at the Paris Exhibition of 1878, which differed considerably from any hitherto made.

Compression.—The important innovation introduced in the Otto engine was the compression of the charge of gas and air before ignition. The advantages of this method have been already described. Beau de Rochas had in 1862 laid down the axiom in his patent that no gas engine could be economical unless its cycle included compression of the mixture after admission. Yet, although the extravagant consumption in gas engines was universally admitted, no one proposed to adopt compression as a means of diminishing it till Otto's engine appeared. Even the inventor himself did not seem to understand the radical nature of the change he introduced. He attributed the reduction in the consumption of gas and the popularity of his engines, not to compression, but to the stratification of the charge as it entered the cylinder. The novel method of admission and ignition was expressly protected in the patents. What-

ever the cause, the success of this engine was from the first undoubted, and practically, for many years after it was brought out, few others were sold to any large extent. For this reason, on account of its excellent design and workmanship, and because the Otto or four-cycle, as it is called, practically superseded all others for many years, it will be useful to consider carefully the constructive details and working of the Otto engine, although it was patented as early as 1876.

Original Otto.—In this motor, the whole cycle advocated by Beau de Rochas is effected in one cylinder, in accordance with his patent. The cycle is divided between four piston strokes, two forward and two back (two revolutions), and one explosion or motor impulse is obtained for every four strokes. The original type of the engine is horizontal, and the end of the cylinder nearest the crank is open. The first stroke of the piston towards the crank (forward) draws in the charge; the second stroke (return) compresses it, and ignition follows at the inner dead point. In the third stroke (forward) the force of the explosion drives out the piston, and in the fourth stroke (return) the products of combustion are discharged. The third is the only motor stroke, in which the pressure of the gases produced by explosion causes them to expand, forcing out the piston, and performing actual work. All these operations are carried out and completed at the end of the cylinder away from the crank, and on one side of the piston only.

At this working end there is a clearance space, comprising originally about four-tenths of the whole volume of the cylinder, into which the charge is compressed, and where ignition takes place. As the piston does not enter this clearance, the gases of combustion can never be completely expelled, but a portion is always left in the compression space to mingle with the incoming charge. Otto considered that it was an advantage thus to retain a part of the products of combustion, to act as a cushion against the piston, and deaden the shock of the explosion. As only one motor impulse is given in four strokes, the motion for the other three must be obtained from the impetus of the moving parts. Hence the fly-wheel is made larger and heavier than usual. There is one other peculiarity of structure to be mentioned, in studying the original Otto type. In most gas motors the charge itself is carried past the flame, or ignited by an electric spark. Here the gas was supplied for three different purposes through separate pipes. There was first the supply pipe, providing gas to mix with air for the charge, and controlled by the governor; another for the permanent outside flame; and lastly, a branch pipe feeding a small intermediary chamber in the slide valve, which communicated first with the outside flame, then with the compressed mixture, and fired the charge. This arrangement has been abandoned in the later engines.

Fig. 34 gives a side elevation, Fig. 35 a plan of an 8 H.P. motor, and Fig. 36 an end view of the Otto engine. The different parts are

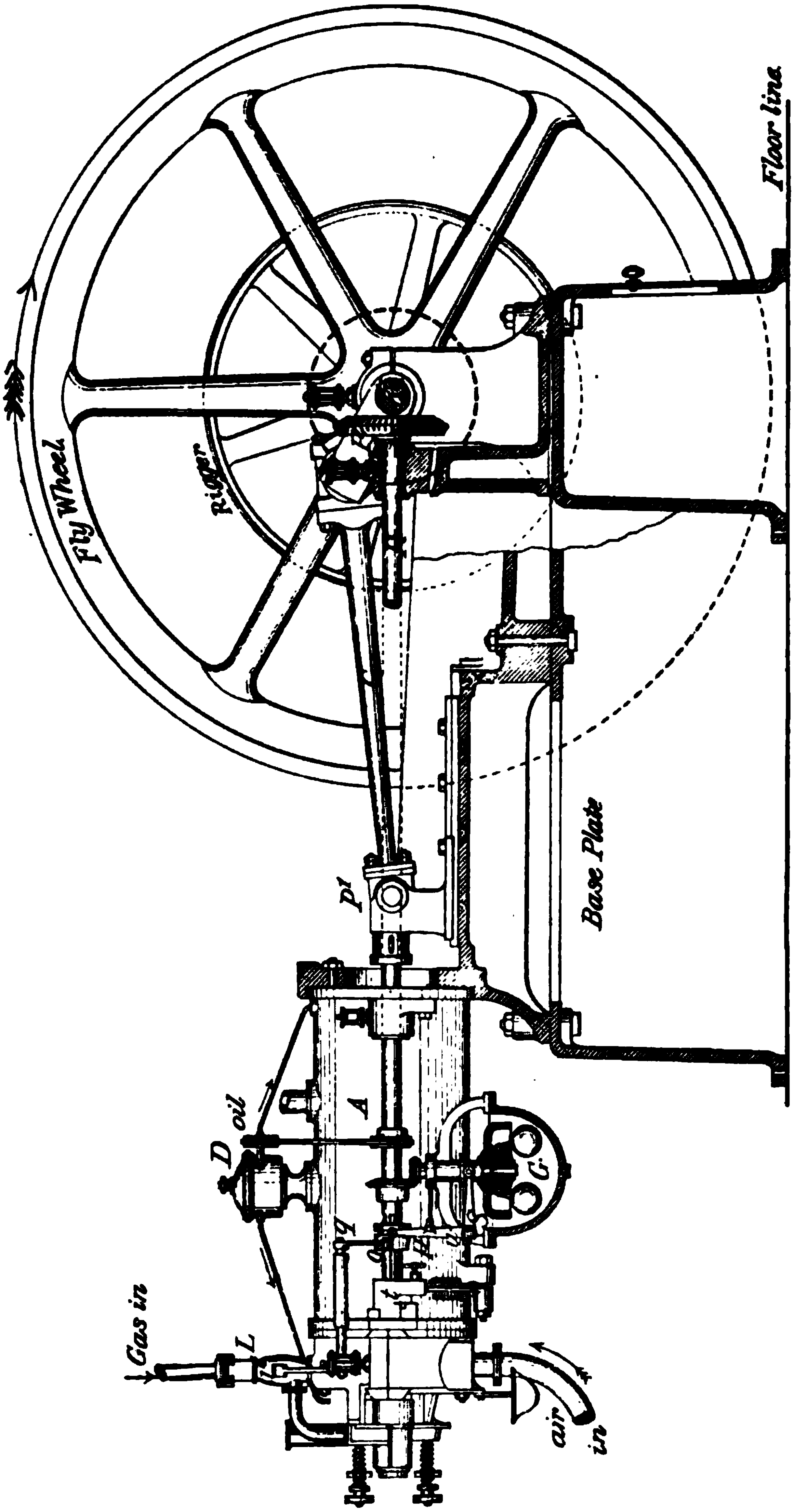


Fig. 34.—Otto Engine, 1876—Side Elevation.

similarly lettered in the three drawings. A is the motor cylinder, and P the piston, shown in Fig. 35 at its furthest point in the in stroke, with

the compression or clearance space behind it. At the crank end the cylinder is open. The piston-rod is keyed to the crosshead P′, to which

Fig. 35.—Otto Engine, 1876—Sectional Plan.

the connecting-rod C, working on to the crank shaft K, is also attached. R is the counter shaft, driven by the wheels E and F from the crank

shaft, and revolving at half the speed of the latter. This shaft R has many functions to perform. Through a crank H and small lever I it drives the slide valve S, where the charge is admitted, ignited, and exploded. Below is the ball governor G, acting upon the gas valve L, and regulating the supply; a cam and tappet *t* upon the counter shaft open the exhaust valve *e* once in every revolution; and, lastly, a strap from it drives the oiling gear D above the cylinder, and supplies oil as long as the engine is working. The cylinder is surrounded by a water jacket W. It has two openings, *a* and *b*—*a* is the charging port, filled first with gas and air at atmospheric pressure from the distributing chamber in the slide valve, and then with part of the compressed charge, and through this port a tongue of flame shoots into the cylinder, and explodes the remainder; *b* is the opening for the exhaust, and the gases of combustion

Fig. 36.—Otto Engine—End View. 1876.

pass out at *e*. Below at *m* is another opening through which air is admitted into the slide valve, mingles with the gas, and is carried forward until, at *a*, it enters the cylinder.

In Fig. 36 the double branching of the gas pipe to supply the permanent outside burner, and the temporary flame, is seen at B′. The slide valve S is worked by crank H and lever I; *e* is the exhaust opened by lever *k*, and the cam *t* on the counter shaft. The governor works upon the gas valve L by a series of levers, *r*, *r*′, while a handle at *r*″ regulates the admission of gas to the valve from the rubber gas bag.

Slide Valve.—The slide valve of this engine is an ingenious piece of mechanism. There is first the face next the cylinder, secondly, the valve proper, and, thirdly, the cover on the outside; the latter is held against the valve by springs and screws. The slide valve alone is driven to and fro; the other parts are fixed. Fig. 37 gives a sectional plan of

the three parts, and their connection with the cylinder. Here A represents the cylinder, E the slide face, S the slide valve, and D the cover. W is the water jacket, *a* the charging port introducing the mixture into the cylinder, *m* the opening in the slide face for admitting the air, which passes at *o* into a chamber in the slide valve with three openings, Q and M, and *n* opening to the slide cover. Shortly after, as the slide valve passes from right to left, the gas is admitted from L in the cover, through *n* into the chamber. Continuing its motion in the same direction, the slide next brings the opening Q of the chamber opposite *a*, and its contents are discharged into the cylinder, to be there compressed by the next back stroke of the piston.

Meanwhile, at the other end of the slide valve, a different series of operations have been taking place at the same time. At B is the permanent burner in the slide cover, open to the atmosphere. While the

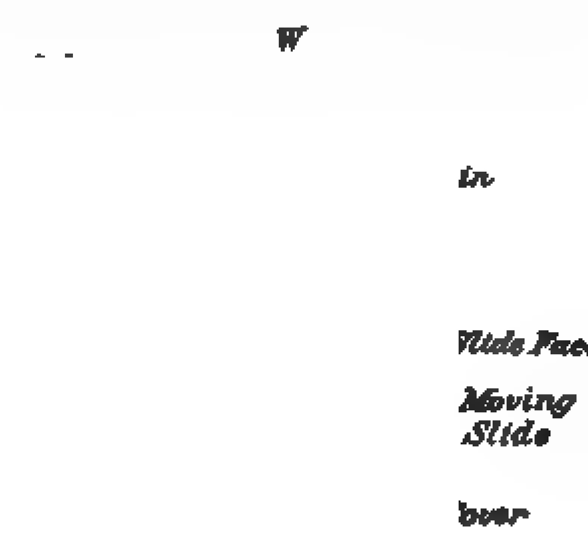


Fig. 37.—Otto Engine, 1876—Sectional Plan of Slide Valve.

slide valve passes from right to left, the chamber N is brought opposite B, but as it contains no gas no ignition occurs. But as soon as it reaches *d*, gas from the third pipe is introduced into it through a grooved hollow in the cover. Before the slide valve commences its return movement, and while the mixture is being compressed in the cylinder, the chamber N is filled with gas from *d*, ignites on passing before B, and when brought opposite the cylinder port *a* fires the charge. It is necessary, however, to equalise the pressure of the gas flame and of the charge, lest the flame be blown out. As long as the small lighting port is in communication with the atmosphere through B the flame is easily maintained, but as the slide moves onward, and connection is cut off, it begins to fail. Therefore, before it reaches *a*, a hole is passed in the slide face, communicating through a T-shaped passage with the charging port. A small portion of the compressed charge passes through it to the flame in N, and establishes

an equilibrium of pressure between the mixture in the cylinder and the flame, before the latter reaches and fires the charge.

Figs. 38 and 39 give a vertical view of the slide and slide cover. In the latter L is, as before, the pipe to admit the main supply of gas, B′ is the smaller gas pipe feeding the permanent flame B, Fig. 37. Through another small pipe the gas passes at *d*, Fig. 39, and through the grooved passage *d′* to the lighting chamber N, Fig. 38. Above this chamber is the hole at *i* through which, and a passage in the slide face, communication is established between the cylinder and the light, as soon as the

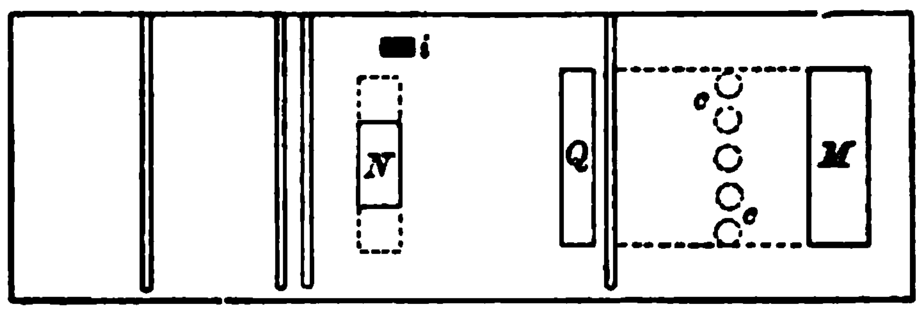


Fig. 38.—Otto Engine—Vertical View of Slide. Valve.

slide passes the opening of the passage. At *c c*, Fig. 38, are the holes for the gas entering the admission and distribution chamber M Q. Figs. 40 and 41 show a vertical section of the slide valve and cover, with the

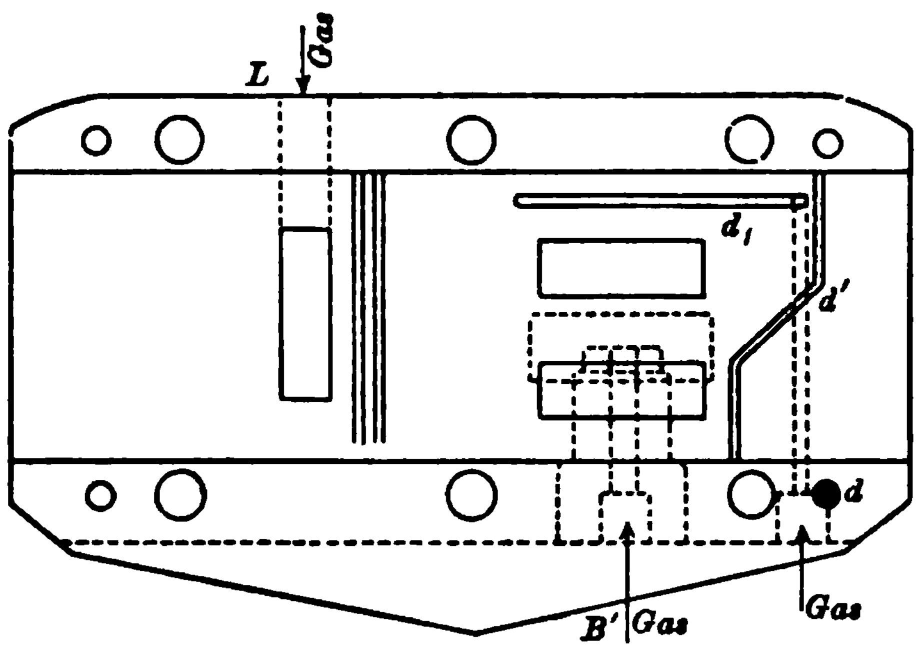


Fig. 39.—Otto Engine—Vertical View of Slide Cover. 1876.

arrangement of the ignition flame. The parts are lettered as before. N is the lighting chamber in the slide, B the permanent burner in the slide cover. In Fig. 40 the flame at N is shown while being formed. Air enters from below, gas through the groove *d′*, corresponding with the opening *d* in the slide cover, Fig. 37, and passes through this T-shaped channel into N. The chamber being in communication with the flame burning in the chimney, the charge in it is ignited. Fig. 41 gives a view of the intermediary flame in chamber N, after it has been cut off from the outer burner, and from the gas pipe *d*. The T-shaped passage

d' here opens on the other side into the cylinder port through *i*, and a small portion of the compressed charge passes through into N. Shortly after, the port is brought opposite the cylinder port *a* and ignition follows. Thus during one piston stroke three operations take place,

Fig. 40.—Ignition Flame and Slide Valve.

Fig. 41.—Ignition Flame and Slide Cover.

and the slide valve has to form and kindle the intermediary flame, equalise the pressure between it and the charge in the cylinder, and ignite the latter.

The method by which all these various actions are timed to occur is ingenious. Fig. 42 gives a diagram of the proportional movements of

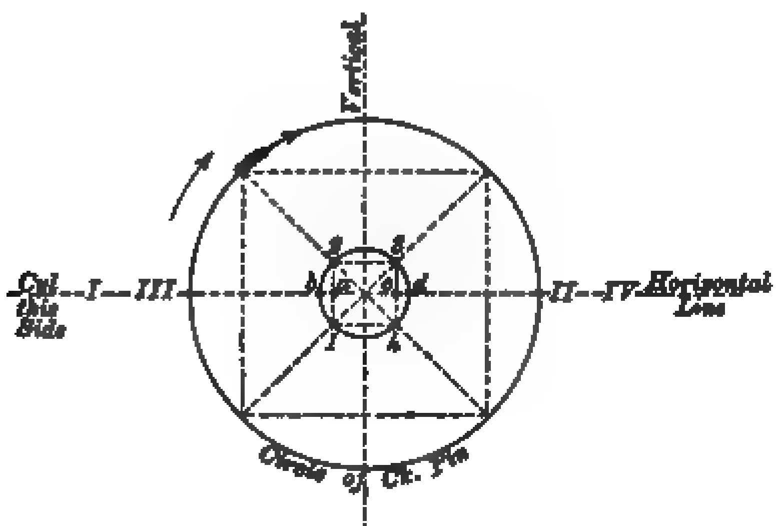


Fig. 42.—Otto Engine—Positions of Crank, Counter Shaft, and Slide Valve.

the motor crank, the counter shaft, and the slide valve. The Roman figures represent the positions of the crank, the Arabic figures those of the counter shaft, while the letters *a*, *b*, *c*, *d* show the movement of the slide valve.

As the motor crank moves from I. to II. in the direction of the arrow, the crank on the counter shaft which is set at an angle of 45° behind it passes from 1 to 2, and the slide valve moves from *a* to *b* and back again. During this time the piston moves out, and the fresh charge is drawn at atmospheric pressure into the cylinder. Fig. 43 gives this position at A. Air is admitted at *m*, gas at N, and both after mixing in chamber M Q (Fig. 37) pass through *a* into the cylinder. The next crank movement completing the first revolution is from II. to III. (Fig. 42); the counter shaft moves from 2 to 3, the slide valve from *a* to *c*. Fig. 43, B, indicates the position of the slide valve. All the ports of the cylinder are closed, while the piston compresses the charge. The lighting chamber is brought opposite the permanent flame and fired, and, through the port for equalising the pressure, part of the charge in the cylinder is also compressed into it by the return movement of the piston. Position III. (Fig. 42) represents the inner dead point; ignition and explosion take place, and drive the piston through its second forward

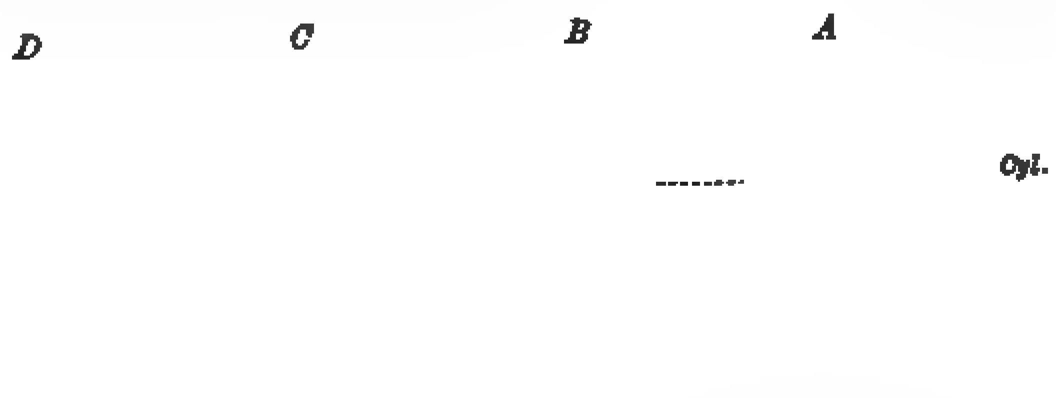


Fig. 43.—Otto Engine—Positions of Ports and Passages. 1876.

and only motor stroke. The crank shaft revolves from III. to IV., the counter shaft from 3 to 4, the slide valve passes from *c* to *d* and back again. Fig. 43, C, shows the progress of the slide during and after the ignition of the charge. From IV. to I. the crank completes its second revolution, the counter shaft passing from 4 to 1 concludes one revolution, and the slide valve moves from *c* to *a* and takes up position D (Fig. 43). All the admission ports are closed to the cylinder, while the products of combustion are driven out through the exhaust by the second return stroke of the piston.

By this arrangement air enters the mixing chamber M (Fig. 37), and is passed on into the cylinder during nearly the whole of the admission stroke, but gas is only admitted during the latter part. The two ports are so proportioned that the ingress of air is first cut off, and gas enters alone at the end of the stroke. The effect of this distribution on the stratification of the charge will be discussed further on. A diagram showing the working cycle in the Otto engine will be found in Roots' *Cycles of Gas and Oil Engines*, p. 47.

Fig. 44 gives a view of the exhaust valve. The lever opening it, K, shown also in Fig. 36, passes beneath the motor cylinder A, and is worked by a cam *t* on the counter shaft R. The end of the lever is held against the counter shaft by a spring. At a given moment the cam *t* presses one end of the lever down, and the other raises the lift valve *s*'; *b* is the opening into the cylinder, and *e* the discharge into the exhaust. When valve *s*' is raised, the action of the piston drives the products of combustion through *b* and *e*. The cam being one-quarter the circumference acts upon the valve during one-quarter of a counter-shaft revolution, or one stroke of the piston. A second cam upon the other side of the shaft can also be adjusted to push down the lever, and hold open the valve, when starting the engine, during the compression as well as the exhaust stroke. This method of diminishing the pressure in the cylinder while starting has been adopted in other engines besides the Otto. The second cam is easily disconnected from the shaft, as soon as the engine is at work.

The speed of the engine is regulated as shown in Figs. 35, 36 (pp. 77, 78). Upon the counter shaft R is a socket with a tappet *o*, having a similar action to the exhaust cam. When the shaft is revolving at ordinary speed, this tappet regularly catches and pushes up one end of the lever *q*, resting upon it, the other end of which terminates in the rod *r*, opening the gas admission valve L. But if the speed increases, the balls fly out and push up another small lever *u*, which, forcing the socket to one side, causes the tappet *o* to miss the end of the lever *q*. Nothing but air is admitted, and no explosion follows until the speed is reduced, and the tappet being again in position acts upon the gas valve. The handle *s* (Fig. 34) is intended to raise the balls only when starting the engine, and falls back automatically after the first explosion.

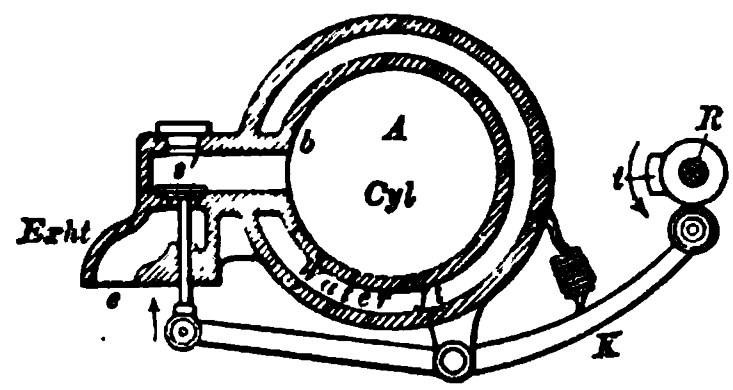
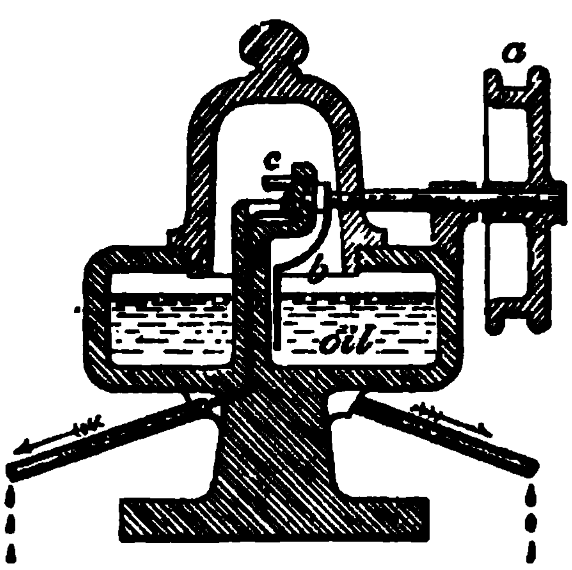


Fig. 44.—Otto Engine—Exhaust Valve. 1876.

Two methods were available for regulating the speed, either to cut off wholly the supply of gas, or to decrease the quantity admitted; the former was preferred as being more economical. No gas could then pass unburnt through the cylinder, but, as an explosion was missed every time the gas valve was closed by the governor, the speed became irregular. Otto was obliged, therefore, to modify the governing gear when the engine was used to drive dynamos for electric lighting, where a very steady speed is required. Instead of the tappet, a cam with graduated steps acted upon the lever *q*. When the speed fluctuated within slight limits, the cam opened the gas valve for a longer or shorter time, and varied the strength of the charge. The explosions were sometimes

weak, sometimes strong, but never wholly missed, unless the speed was so greatly increased that the wheel of the lever slipped quite off the cam. Latterly, for small motors, Otto adopted the pendulum type of governor, which is frequently met with in modern engines. It consists of an oscillating weight at the end of a rod, swinging backwards and forwards with the motion of the engine and of the slide valve, to which it is attached. As long as the speed is normal, a horizontal rod, connected to the pendulum, fits at each revolution into the notched end of the valve-rod opening the gas valve. But if the speed and the motion of the slide valve increase, the swing of the pendulum cannot overtake them. The weight shifts the rod out of position, a miss fire occurs, and no gas is admitted until the speed of the engine is reduced.

The lubrication of the Otto engine is simple and ingenious. Great care was necessary in oiling all the parts, especially the slide valve. Fig. 45 shows a vertical section of the oiling apparatus. An external view, with the two lubricating pipes, is shown at D, Fig. 34 (p. 76). This apparatus is worked by means of a small pulley *a* and a strap on the counter shaft. The cup is filled with oil into which a small wire *b*, on the same shaft as the pulley, dips at every revolution. The drop is wiped off on a fixed pin *c* placed over a trough. From the trough it runs into one of the two pipes, and is carried either to the piston or the slide valve. Sometimes this arrangement is made in duplicate, and the cup divided vertically. Two kinds of oil can then be used at the same time, the better quality for lubricating the slide valve, and a coarser oil for the piston. In this apparatus the oil is kept cool, and lubrication is automatic and continuous.



Sectional elevation.

Fig. 45.—Otto Gas Engine—Oiling Apparatus.

For starting small power engines, the additional cam to keep the discharge valve open during compression as well as exhaust was found sufficient. But the Otto motors were soon applied to larger powers, and it then became impossible to start them without a special apparatus. Compressed air is now chiefly used. It is forced by a small air pump driven from the engine, or from an auxiliary motor, into an air-tight reservoir, and stored ready for use.

Few engines more ingeniously constructed than the Otto have yet appeared, and the cycle has now been extensively adopted by many other firms. More than 30,000 engines were sold in the first ten years, and according to the German firm 45,000 engines, with a total of about 200,000 H.P., had, up to about 1895, been constructed by them. Considerably more than 100,000 engines are now at work.

Otto himself attached, as we have said, the greatest importance to his system of admitting the charge. The slide valve is so constructed that pure air enters first, and mingles with the products of combustion left from the previous charge, which the piston cannot expel. Gas next enters the slide valve and mixes with the air, forming a charge in the proportions of about 7 of air to 1 of gas. Finally, by the movement of the slide valve, gas alone is admitted into the cylinder, feeds the burning light, and causes it to shoot into the poorer mixture like a tongue of flame. Thus there are three strata in the cylinder, of three different degrees of richness, and the flame is supposed to leap from one to another, producing the slow combustion so much desired by Otto. Many eminent scientific men supported his theory of stratification, while others were strongly opposed to it, and it has now been discarded.

The patents for the Otto engine, which have long since expired, were formerly acquired in England by Messrs. Crossley, of Manchester; in Paris, by the Compagnie Française des Moteurs à Gaz; in America, by Schleicher, Schumm & Co., of Philadelphia. The German firm have long been established at Deutz, near Cologne.

Several of these firms, while adhering to the principle of the original type, have made many alterations in the working details. Ignition by a hot tube has been substituted for the flame carried in the slide valve. Fig. 46 gives two views of this method of ignition, as used for many years; it has recently been again modified. C is the passage into the cylinder, T the cast-iron tube, and R the asbestos lining of the chimney. The tube is closed at the top, and kept at a red heat by a Bunsen burner B. During the compression stroke a cam on the counter shaft lifts the lever L, and pushes up the timing valve E into the port D. No portion of the compressed charge can, therefore, enter the tube, and any burnt gases left in it escape through A into the atmosphere. At the inner dead point, when the piston has completed the compression stroke, the cam leaves the lever L free, E is drawn down by the spring S, and the compressed mixture, rushing into the red-hot tube, is there fired and ignites the charge. G and F are outlet channels for discharging the burnt gases through A. Thus a rich mixture alone enters the tube, and

Fig. 46.—Otto Engine—Ignition Tube. 1888.

ignition is certain. By this method the pressure of the charge is utilised, and is made to fan the flame instead of blowing it out. Porcelain tubes are now generally used in the Crossley-Otto, as in most other English gas engines, and the top of the tube is often left open to the air. On the Continent, the charge, except in very small engines, is always fired by electricity. Messrs. Crossley and Holt are also said to have been the first to introduce the pendulum governor, and Mr. Holt brought out an ingenious oiler, which lubricates according to the amount of work on the engine.

As the Otto engine became more popular, and larger sizes were made, the cost of working it with town gas was found to be heavy, and several methods were introduced for making gas more cheaply than by distillation from coal. These will be described later on; the system most generally used is Dowson's cheap gas producer, which reduces considerably the cost of working an engine, as compared with town gas. This gas, generated on the spot, is, however, economical only when employed for larger engines. As it is much poorer than lighting gas, it requires to be diluted with a smaller proportion of air; the ratio is generally about 1 of Dowson gas to 1½ of air.

Deutz-Otto.—For powers over 20 H.P., the makers of the Otto brought out engines having two cylinders side by side, and two sets of valves, driven from an auxiliary shaft placed between them. One governor regulated the speed. The two motor cranks worked on one shaft, and were 180° apart, thus giving a motor impulse alternately from each piston for every revolution of the crank shaft. A two-cylinder engine indicating 30 H.P. was shown at the Electrical Exhibition at Frankfort in 1891. Gas was supplied from a receiver controlled by the governor, which could be disconnected from one cylinder, and made to act upon the other only, if less power was required. At Chicago the Deutz firm exhibited seven gas engines from 2 to 20 B.H.P., besides oil motors. A vertical 6 H.P. engine, driven either by gas or oil, and running at 360 revolutions per minute, was also shown. It had no timing valve or side shaft, and the exhaust only was driven by an eccentric, the other valves being automatic. A flexible membrane connected to the exhaust valve, and depressed during each suction stroke, was acted on by the governor, and this method of regulating the speed is still retained in a few small engines. Automatic valves have now been discarded, and the valves of all modern Deutz engines are driven from the cam or valve shaft, geared two to one to the crank shaft.

In governing the engine, the hit and miss principle has been practically abandoned. Until recently the governor acted on a stepped cam, and reduced the admission of gas, a proportionally larger volume of air being admitted. Thus the quality of the charge was varied, but the quantity,

and therefore the compression, remained the same. In the latest type, as shown at Fig. 47, which is a section through the cylinder head, the spindle of the admission valve carries the gas valve, and a piston valve to admit the air, and the three open simultaneously. The governor, driven from the valve shaft, acts upon a bell crank carrying a lever, the fulcrum of which is connected to the rod opening the inlet valve. The position of the fulcrum is shifted by the governor according to the load. The valve

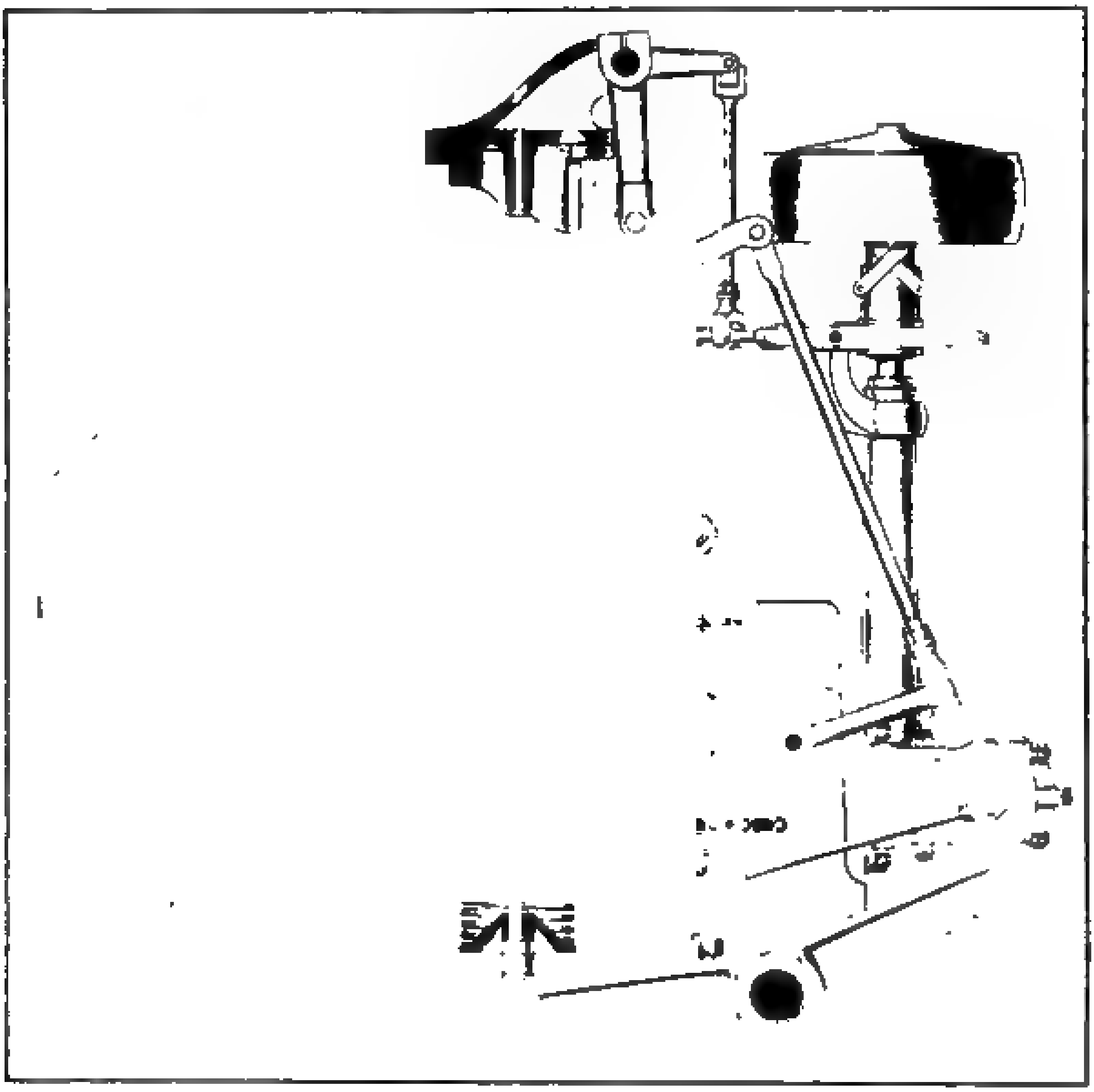


Fig. 47.—Deutz-Otto Gas Engine—Section through Cylinder Head.

is held open for as long a time as before, but the governor acts upon the lift—*i.e.*, the descent of the valve, throttles the charge, and thus varies the quantity of gas and air admitted to the cylinder. As the proportions are not affected, an explosion, weak or strong, is always obtained. Ignition is by electricity, a magneto-electric machine and contact breaker being generally used. In all the larger engines the valves, cylinders, and covers are separately cooled, and the exhaust valve is often relieved by admitting compressed air beneath it. Both sight feed and crank-pin lubrication are

employed, and the consumption of oil is said not to exceed 1 to $1\frac{1}{2}$

Fig. 48.—Deutz-Otto Double-acting Engine.

grammes per B.H.P. hour. All engines above the smallest sizes are started by compressed air admitted behind the piston, which after two or three revolutions communicates sufficient impulse to the engine to draw in a charge of gas and air, and the usual cycle commences. A friction coupling, preferably on the crank shaft, is generally necessary to enable the engine to start without a load, but other means are sometimes adopted. All Deutz engines are now made horizontal, except a small vertical type, with hot-tube ignition, in sizes from 1 to 5 H.P., which runs at 250 revolutions per minute. Horizontal engines are single cylinder up to 160 H.P., with a speed of 250 to 170 revolutions per minute; above this size they have two cylinders side by side. The single-acting tandem arrangement has now been abandoned in favour of the new double-acting type.

This interesting engine, shown at Fig. 48, resembles a horizontal steam engine, with cylinder closed at both ends; the four-cycle has, however, been retained, and is carried out alternately, on either face of the piston. The thrust of the piston working through stuffing-boxes is taken by the crosshead and connecting-rod, as shown. The cylinder is longer than in the single-acting type, to allow space for the double set of admission and exhaust valves, the ignition, and the starting valves, which are placed one above the other at either end. The governor acts upon the admission valve-rod, and varies the lift by adjusting the fulcrum of the admission lever; in this as in other respects the action is similar to that of the single-acting Deutz engine. Especial care, as in all double-acting motors, is bestowed on the cooling water system. The cylinder, cylinder covers, valve chest, and exhaust valves are all separately cooled, and the temperature of each independently regulated. The piston-rods are hollow, and both pistons and rods are cooled by water at a pressure of 35 to 40 lbs. per square inch, supplied in some engines by a separate pump. Another pump delivers oil under pressure for lubricating the cylinder, pistons, and stuffing-boxes. The engine is made in sizes from 150 to 1,500 H.P. with one cylinder, and from 300 to 3,000 H.P. with two cylinders, either tandem or side by side. For larger powers up to 6,000 H.P. two tandem engines side by side are used. Up to the present (1905) the Deutz firm have made, or have in hand, 45 of these double-acting engines, with an aggregate of 21,350 H.P., to work with blast furnace, coke oven, brown coal, Dowson, or suction-producer gases. Of single-acting engines above 100 H.P. they have, during the past ten years, constructed 175, developing 37,000 H.P. The consumption of lighting gas of 560 B.T.U. per cubic foot heating value varies from 15 to 24 cubic feet, according to the size of the engine. There are now 70,000 Deutz engines at work, giving a total of 400,000 H.P.

Crossley-Otto.—The Otto engine, described in detail in the beginning of this chapter, is of the original type brought out in 1876,

and various modifications and improvements have since been made, especially by Messrs. Crossley. For all sizes of their engines the slide valve has now been abolished, and air and gas are separately admitted through lift or mushroom valves, worked by cams on the valve shaft, which is driven by worm gear two to one from the crank shaft. The exhaust valve, worked by a cam and levers, has been retained. In their large power engines the exhaust valves and spindles are made hollow, and cooling water is circulated through them. Sometimes equilibrated exhaust valves are used, and the mushroom valve is balanced by a piston valve sliding to and fro, the pressure above and below being equalised by a hole through the stem of the valve. The back pressure in exhaust valves of large dimensions is always considerable, and various methods of overcoming it are employed. Ignition by hot tube, instead of a flame in a cavity, has been already described. Communication between the cylinder and the tube, for all sizes of Crossley engines above 8 H.P., is made through a timing valve worked by a cam, but in the larger engines, especially if driven by producer or blast-furnace gases, electric ignition is preferred.

Messrs. Crossley have been among the first to recognise the necessity of great accuracy in governing gas engines, especially if intended to drive dynamos for electric lighting. Pendulum or rotary ball governors are used, and in the latest types for large engines the quantity, but not the quality of the charge varies with the load. To produce this result a cylindrical cut-off valve, placed between the gas and air valves and the admission valve, slides to and fro inside the latter, and carries ports corresponding with others in the casing of the admission valve. The exact moment of uncovering these ports is determined by the governor acting on the pivot of the eccentric working the cut-off valve. Two methods of lubrication are adopted, and both are used in the larger engines. The crank pin dips at each stroke into an oil bath in the base, and oil is thus continuously supplied to the internal working parts; and it is furnished to the external parts from sight-feed lubricators. Most Otto engines are provided with a safety apparatus to prevent them from starting backwards, and many have special starting gear. Larger sizes are started by compressed air, as described, no explosions being permitted till the piston has moved out.

Messrs. Crossley have now given up the two-cylinder type side by side, described at p. 86, in favour of the end to end arrangement shown at Fig. 49. In this engine both connecting-rods work on to the same crank, and an explosion is obtained at every revolution. It is made from 160 to 540 B.H.P., and runs at 160 revolutions per minute with lighting

Fig. 49.—Crossley Horizontal End to End Engine, 500 H.P.

gas. Fig. 50 shows the latest design of their smallest horizontal engine, giving 1 and 2 B.H.P. with a speed of 330 revolutions per minute. Engines for electric lighting are made from 400 to 500 B.H.P., to work with town or producer gas, and nearly 10,000 H.P. have been supplied for this purpose, generated by single-cylinder, two-, and four-cylinder engines. For working hoists, pumping water or sewage, they are sometimes coupled direct on one base plate. One of the latest types is a vertical engine with two inclined inverted cylinders, developing with producer gas 55 H.P. Each cylinder has an automatic cut-off valve, acted on by the governor, which regulates the supply of air and gas without cutting out explosions. Ignition is by a porcelain tube with a timing valve. Mention must also be made of a compound gas engine brought out in 1900, with two outer high-pressure cylinders, and a low-

Fig. 50.—Crossley Horizontal 2 B.H.P. Engine. 1905.

pressure cylinder between them. Each cylinder is coupled to a separate crank, and gas is admitted through a reciprocating valve, moving at half the speed of the engine. In a trial made in September, 1900, the consumption of lighting gas was 14·8 cubic feet per B.H.P. hour, but the economy realised did not compensate for the increased cost of construction, and the type has not been repeated.

Of large power Crossley engines a 1,000 H.P. plant driven with producer gas is now working. An important and typical example of a pumping plant at Madely in Shropshire is described in *The Engineer*, February 6, 1903. There are two 90-H.P. Crossley engines, and two Dowson generators, the plant being in duplicate to avoid any stoppage in the water supply. Engines developing more than 3,000 H.P. are now at work with Mond gas, and nearly 50,000 engines are said to be now running (1905), 38 of which give over 200 H.P. each.

An ingenious arrangement was introduced some years ago by Mr. F. W. Crossley and Mr. Atkinson (who is now with the firm), which, although no longer used, was one of the first attempts to procure a scavenger blast of air, and cleanse the cylinder of the products of combustion. The exhaust pipe was lengthened to about 65 feet, and the admission of the charge was slightly modified, the air valve being opened in advance of the gas valve, and a little before the end of the exhaust stroke. The pressure of the gases in the cylinder combined with the speed created by the long exhaust pipe to cause a strong current of fresh air through the compression space, sweeping out the burnt products, and cleansing the cylinder from the residuum of the former charge, before the gas valve opened and a fresh mixture began to enter. The process was assisted by the partial vacuum caused by the reduced pressure in the cylinder.

A scavenger charge is now recognised as of special advantage in engines worked with Dowson or other power gas, and renders ignition more certain and regular, independently of the varying quality of the gas. The volume of cold air drawn in also helps to cool the cylinder walls, and a higher compression pressure can be attained. In a test carried out by Messrs. Crossley and Atkinson in 1894, the engine with their system of scavenging developed 39·9 H.P. on the brake, 46·45 I.H.P., and showed a consumption of 14·5 cubic feet of Openshaw gas per I.H.P., and 16·48 cubic feet per B.H.P. hour. It ran at 173 revolutions per minute, the mechanical efficiency was 86 per cent., and thermal efficiency per B.H.P. 24 per cent. The heating value of the gas was taken at 640 T.U. per cubic foot.

The Otto engine is made in France by the Société Française des Moteurs à Gaz et des Constructions Mécaniques, and is constructed horizontal with one or more cylinders. A two-cylinder engine, giving 300 H.P., or 150 H.P. per cylinder, has been made by them to work with blast-furnace gases, and also another of double the power, with four cylinders of equal diameter, and two cranks. Their latest plant, intended for the Société des Aciéries de Longwy, consists of three sets of blowing engines and gas engines, driven by blast-furnace gases, and developing 1,200 H.P. One of these, which is already at work, comprises two twin-cylinder double-acting engines, working the blowing engines direct through a prolongation of the piston-rod. The cylinders, cylinder bottoms, stuffing-boxes, and exhaust valves are all cooled with water.

Trials.—More experiments have probably been made on the Otto than on any other gas engine. Details of these will be found in the Tables, but a few of the earlier are here summarised. The earliest published trials were carried out by MM. Brauer and Slaby, in Germany, in 1878. The engines indicated 3·2 H.P. and 6 H.P.; the

first ran at 180 revolutions, the second at 159 revolutions per minute. Between 38 and 40 cubic feet of gas were used per I.H.P. per hour. This was a large consumption for an Otto engine, though at the time the economy, as compared with the expenditure in other motors, was striking. For the next ten years the consumption of gas gradually diminished, as various improvements were effected in the engines, and the amount used varied inversely with the size of the engine tested. In an experiment* by Dr. Slaby in 1881 on a 4 H.P. engine, making 157 revolutions per minute, the gas consumption was 28·3 cubic feet

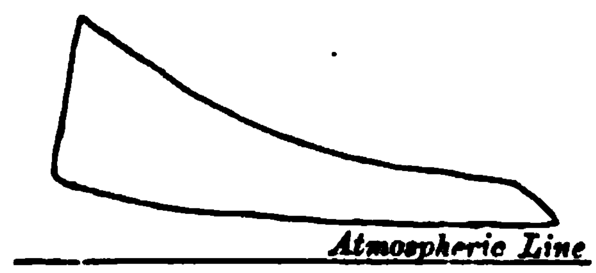


Fig. 51.—Otto—Indicator Diameter. 1881.

per I.H.P. per hour. An Indicator diagram of this trial is given at Fig. 51. A 14 I.H.P. engine, tested by Garrett, consumed 19·4 cubic feet of Glasgow gas per I.H.P. per hour (diagram Fig. 52). An early trial was made by Teichmann & Böcking in 1887 on an Otto engine of 50·8 B.H.P., using Dowson gas, in which the consumption was 103 cubic feet per hour per B.H.P. In 1881 a series of trials was carried out at the Crystal Palace by Professor Gryll Adams on Otto engines of various powers.

In 1888 a series of trials of motors for electric lighting was made in London, under the auspices of the Society of Arts, and a 9 H.P.

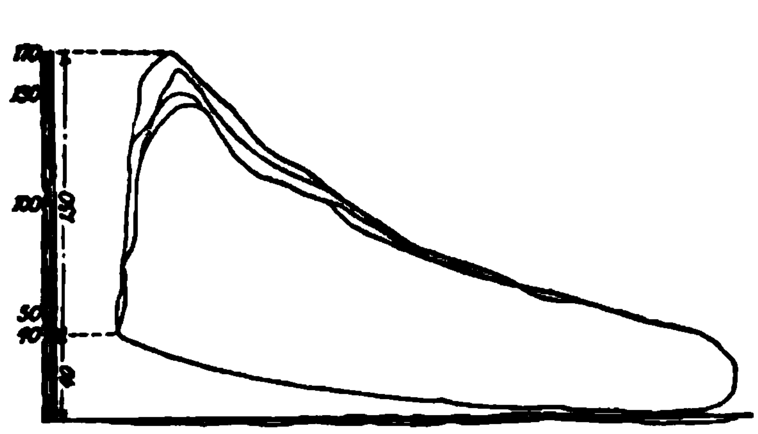


Fig. 52—Otto—Indicator Diagram. 1887.

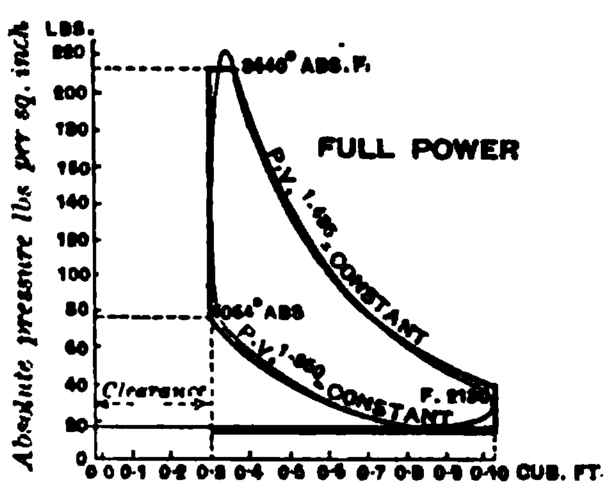


Fig. 53—Otto—Indicator Diagram. 1888. *Soc. Arts.*

Otto-Crossley, an 8 H.P. Griffin, and a 6 H.P. Atkinson engine were tested under the following heads:—Regularity of speed under varying loads; power of automatically varying the speed; noiselessness; cost of construction, of maintenance, and of fuel. All three engines worked satisfactorily. The lowest consumption of gas was obtained

* Full details of this experiment will be found in the Appendix to Professor Fleeming Jenkin's Paper on "Gas and Caloric Engines." Lecture delivered before the Institution of Civil Engineers, 21st Feb., 1884.

with the Atkinson engine, but the Griffin ran with great regularity, and the Otto was also economical. The gas used in all the trials (Gas Light & Coke Co.) was analysed, and its mean heating value determined at 629 B.T.U. per cubic foot. The quantity of jacket water per hour was noted, as also its temperature on entering and leaving the jacket, and each of the engines was tested at full power, at half power, and running empty. Fig. 53 gives a diagram of the Otto engine taken during the trial.

In a trial made in 1895 by Professor Köhler, the consumption in a 30 B.H.P. Deutz-Otto engine, running at 200 revolutions per minute, was 16·9 cubic feet per B.H.P. per hour of gas, having a heating value of 560 B.T.U. per cubic foot. Details of most of the modern trials will be found in the Appendix.

A description of the Lanchester self-starter is given at p. 90 of the Third Edition. It is now no longer used, except to start certain sizes of the Robey engine (see p. 119).

CHAPTER VII.

MODERN BRITISH GAS ENGINES.

CONTENTS.—Modern Gas Engine Development—Compression—Governing—Tangye—Stockport—Acmé—Fielding and Platt—Premier—Campbell—Westinghouse—Forward—Midland—Trusty—Robey—National—Griffin—Clarke-Chapman—Gardner—Roots—Dudbridge—Newton—Birmingham—Globe—Ideal—Small Engines—Vogt.

Two circumstances have chiefly contributed to the great development of gas engines within the last few years in England. The first is the extensive and increasing application of electricity to lighting, and the demand which has arisen for gas engines to drive dynamos in country mansions, &c., as being more suitable and economical than steam. No cost is incurred with gas engines when not running, and as it is seldom necessary to furnish power for electric light for more than a few hours at a time, a gas motor, easily started and stopped, is preferable to a steam engine and boiler. The economy of gas engines for electric installations is also marked, even where town gas is used. Sir W. Siemens was the first to draw attention to the fact that coal gas gives more light when furnishing power electrically through a gas engine and dynamo, than when the same quantity of gas is burnt in the ordinary way. At Dessau in Germany an electric light installation has been driven by engines worked with town gas since 1886. Where gas generators are used supplying Dowson or other power gas to the engines, the economy is much greater, the fuel costing less than half that required in a steam engine and boiler, to give the same power. All the larger firms, both in England and on the Continent, make gas engines for electric lighting, and installations of this kind, worked with Dowson, Mond, or other producer gas, are now too numerous to specify.* These engines run at a higher speed than ordinary motors, and the governing is more delicately adjusted, to vary the quality and quantity of gas admitted.

The expiration of the Otto patent also gave an additional impetus to the manufacture of gas engines. Hitherto the four-cycle has been found the simplest type, working practically with as much economy as others of more elaborate construction. Some authorities are almost inclined to regret its universal adoption, as tending to check the invention of new types. Progress has consisted rather in perfecting the mechanical details of existing engines, than in the production of novelties.

* More than 500 Electrical Works in Germany are now worked with gas engines driven by producer gas.

Since the beginning of this century, however, double-acting engines, more or less on the Clerk system, with motor cylinder and pump, have come much to the front. The development of gas engines in England is shown by the fact that the output is estimated by Mr. Clerk at about 100,000 motors, with an average of 20 H.P.*

Special features in the latest development of internal combustion engines are their great increase in size, increased compression, and improvements in construction. It has been more fully realised that the future of large gas engines lies chiefly in adapting them to work with gases of poor quality, such as Dowson, Mond, or blast-furnace gases, and this has necessitated a much larger type of engine. Distinct progress has been made in double-acting and two-cycle engines. Of the latter the most notable examples are the Koerting and the Oechelhaueser. The Deutz firm in Germany, the Cockerill in Belgium, and the Letombe in France have introduced a double-acting type, but it has not hitherto found much favour in England. Double-acting engines give larger power for the same size of cylinder, greater uniformity in running, and a better mechanical efficiency, but the working parts must be carefully cooled. Two-cycle engines necessitate the complication of pumps, and for this reason they have practically been given up for small powers, but for large engines, in which a second cylinder is almost indispensable, they have proved very successful. An eminent German authority, Herr Koerting, distinguishes four types of gas engines, viz.:—

1. Four-cycle, single cylinder, single-acting. (Example, Cockerill.)
2. Four-cycle, single-acting, multi-cylinder. (Example, Deutz-Otto.)
3. Two-cycle, single-acting, single cylinder. (Example, Oechelhaueser.)
4. Two-cycle, double-acting, single cylinder. (Example, Koerting.)

Another point to be noted in large power engines is the arrangement of the cylinders, and the power allotted to each. The Deutz firm consider that not more than 250 to 300 H.P. should be assigned to each cylinder, and with this view most English firms agree. Greater regularity in running, and more reserve of power is said to be obtained by this multiplication of cylinders. The Cockerill firm, on the other hand, develop up to 600 and 700 H.P. in one cylinder, and a few foreign firms follow them. A 750 H.P. Nuremberg engine is probably one of the largest single cylinder motors now at work. The introduction of the two-cycle type, especially when double-acting, will probably materially affect this question.

In the arrangement of the cylinders three systems, known as the side-by-side (or twin), the end-to-end, and the tandem, have been adopted.

* See Mr. Dugald Clerk's valuable paper on "Internal Combustion Motors," "James Forrest" lecture, Institution of Civil Engineers, 1903-1904, and Mr. H. A. Humphrey's pamphlet, *Recent Progress in Large Gas Engines.*

In the first the pistons of the two cylinders work on to two cranks at the same angle, the flywheel being generally between them. The four-cycle is carried out successively in each cylinder, the admission stroke taking place in one, the expansion stroke simultaneously in the other, and an explosion is obtained at every revolution. This arrangement is now perhaps the most usual. In the end-to-end type the cylinders are opposite each other, and both pistons work on to the same crank, at an angle of 180°. The admission stroke in one corresponds with the compression stroke in the other, and there are two explosions during one revolution, and two negative strokes during the next. In the tandem system, which is much used both in England and abroad, the two cylinders are placed one behind, and in line with the other, and both pistons work on to the same crank. An explosion per revolution is obtained alternately in one or the other cylinder, and the admission stroke in one corresponds with the expansion stroke in the other. This arrangement necessitates a stuffing-box between the two cylinders, and the valves are not easily accessible.*

The advantages of compression have also been more fully realised, and pressures have notably increased. Compression pressures of 120 lbs. per square inch are now usual in Crossley engines; in the Koerting they are carried to 160 and 180 lbs., and in other foreign engines even higher. If to increase compression the clearance space be reduced within very small limits, the quantity of inert gases remaining in the cylinder at exhaust will also be diminished. With this question, that of the ignition of the charge is closely connected. Beyond a certain limit increased compression may, if the engine be driven with lighting gas, produce premature ignition. To avoid this difficulty two methods have been employed, the introduction of a "scavenger" blast of air ("Spülluft"), as in the Premier, and to a certain extent in the National, the Koerting, and the Oechelhaueser; and the injection of water, adopted in the Bánki. With poor gases this danger is minimised, but in all large engines ignition by hot tube, especially abroad, has practically been abandoned in favour of electricity, which may be relied on to ignite the charge, without danger of miss-fires. Ignition tubes cannot be used in engines driven with blast-furnace gases, because the dust in them acts injuriously on the material of the tubes.

Among recent improvements one of the most notable has been the greater attention bestowed on governing the engine. The admission of the charge is regulated with almost the same precision as in a steam

* See on these subjects two excellent German pamphlets, Professor Meyer, "Grosse Gasmotoren," *Zeitschrift des Vereines deutscher Ingénieure*, vol. xliii., and Herr Karl Reinhardt, "Verschiedene Constructionen von Grossgasmotoren," *Stahl und Eisen*, 1902, Nos. 21 and 24.

engine, with which the best gas motors can now fairly compete in regularity of running. Governing on the "hit-and-miss" principle was formerly the rule in engines driven with lighting gas, that no gas might be wasted. Now that cheaper gases are utilised, economy of consumption is not so necessary as steadiness in running. The quantity of air admitted being less, and of gas much more, it is comparatively easy to reduce the richness of the charge without cutting out ignitions. In one respect gas engines may even be more easily governed than steam engines, because each cylinder being a motor cylinder, the governor can act directly upon it. As a rule, a throttle valve of some kind is used, through which the governor regulates the amount of the charge admitted to the cylinder, and hence the compression, and the power developed. Sometimes the quality, but not the quantity, of the charge is varied, the degree of compression remaining constant. With this method variations in the load do not affect the quiet running of the engine. German authorities, who are strongly in favour of electric ignition, claim to run even small engines economically with it, because if the governor reduces the quantity of gas and air admitted, but not their proportional volumes, the charge will always ignite. Practically, therefore, the consumption of gas for the power developed will be no more than when the governor wholly cuts off the supply.

The cooling of the working parts is another point of much importance. The great heat developed, especially in double-acting engines, makes it necessary to cool, not only the cylinder, but the piston, piston-rod, and valves. The quantity of cooling water and method of applying it are now carefully regulated, and the temperatures in the cylinder thus controlled. As the ratio of wall surface to cylinder volume does not increase in the same proportion as the size of the cylinder, the cooling water jacket cannot exert the same effect on the charge in large as in small engines. The expansion of the inner cylinder walls exposed to the maximum heat of explosion is greater than that of the outer walls in contact with the jacket water only, while that of the piston is greater than either, and more care is required in cooling it. In engines above 150 H.P. the piston-rod and the spindle of the exhaust valve are generally made hollow, and the piston separately water-cooled. Large engines have sometimes two exhaust valves, one opening before the other, or balanced valves, to divide the power necessary to lift them.

Lubrication is also an important matter, and is generally supplied to some parts of the engine under pressure from a pump. Crank-pin lubrication is also the rule for large power engines. The difficulty of starting has now been practically overcome, and the various types of self-starters, as the Lanchester and Edmondson, are seldom used. Starting by compressed air, except in the Cockerill engines, is universal, and the process

is simplified where there are several cylinders. Compressed air from a reservoir, supplied either by an auxiliary motor or by the engine itself, is admitted into one or more cylinders, and as soon as an impulse is obtained, a charge of gas and air is sent into another cylinder, and the engine starts.

Another noteworthy feature is the increased tendency to base the work of an engine on its heat efficiency—that is, the number of heat units it is capable of turning into useful work. Most of the important gas engine makers now state the consumption of their engines in heat units per H.P., independently of the combustible used.

Mention must lastly be made of the great development in gas producers, and the introduction of suction producers, a description of which will be found at p. 202. The problem of utilising bituminous coal in both types of producers is also now carefully studied both in England and abroad, and several successful attempts have been made to deal with it.

Tangye.—This important firm have ceased to construct the engine described at p. 58 (Robson's patent), and since 1891 have made engines only on the Otto four-cycle principle, with Pinkney's improvements. Next to Messrs. Crossley they at present build some of the largest motors in England. Their single-cylinder horizontal engines range from 2½ to 340 B.H.P. with lighting gas, and the maximum piston speed in them is 750 feet per minute. The smaller sizes have no timing valve, punctual ignition being obtained by adjusting the chimney of the tube. In the larger horizontal engines porcelain tube igniters are used. The combustion chamber is carefully constructed to prevent shock, and render the engine suitable for driving a dynamo direct, and also to ensure steady and complete combustion of the charge during the whole of the motor stroke. The cylinder casing, combustion chamber, and exhaust valve-box are all made in one casting.

Messrs. Tangye have lately introduced a new vertical type, especially adapted for driving dynamos, with two or three cylinders, developing from 32 to 340 B.H.P. with town gas, and 27 to 320 B.H.P. with producer gas. The speed is about 250 revolutions per minute. The charge is fired by a small magneto-electric machine. As there is an explosion in each cylinder every second revolution the crank receives a motor impulse at each two-thirds of a revolution, and increased steadiness in running is thus obtained. Compression in the Tangye engine is kept within moderate limits; in a trial by Professor Witz of a 26 B.H.P. engine, details of which will be found in the Tables, the mean pressure at ordinary load was about 84 lbs., and at maximum load 97 lbs. per square inch. The smaller engines are started by hand, in the larger a low-pressure starter is used, and a charge of gas and air sent by a small hand pump into the cylinder. For powers above 80 H.P. the engines are

started by compressed air from a reservoir charged either by a small starting engine, or the main engine. Governing is on the "hit-and-miss"

Fig. 54.—Tangye Horizontal Engine.

principle in the horizontal engines, a sensitive centrifugal governor being used. By an ingenious arrangement the next impulse after a missed explosion is stronger than usual. When the governor cuts out the supply of gas, the air, which alone enters the cylinder, drives out the products of combustion. The governor then moves up a small wedge, opening the gas valve more than before, and a specially rich charge is obtained. In the vertical type the governor on the flywheel acts by throttling the admission valve, and varies the quantity of the charge admitted, the proportions of gas and air remaining the same. Both the compression pressure and the strength of the impulse are thus reduced according to the load. The lubricating oil is contained in a receiver in the base, into

Fig. 55.—Tangye Three-cylinder Vertical Engine.

which the end of the connecting-rod dips, and throws the oil over the working parts.

A large Tangye gas plant was erected in 1903 for the Ryde Electrical Works. There are two sets of three-cylinder vertical engines driven by producer gas from a Tangye generator; the consumption is about 1·9 lbs. anthracite per unit of electricity. The engines have two horizontal cam shafts driven from one vertical side shaft; the lower carries cams for opening the three exhaust valves. The upper shaft has two cams for each cylinder, one for breaking contact and producing the electric spark, the other works the admission valves.

Messrs. Tangye make gas producers as described at p. 210, and have lately brought out a suction gas producer (see p. 211). The consumption in their larger engines per B.H.P. hour is about 14½ cubic feet of lighting gas of 700 B.T.U. per cubic foot. Fig. 54 shows a horizontal engine developing 186 H.P., with water-cooled piston and exhaust valve; Fig. 55 the new vertical three-cylinder type. They have supplied 500 H.P. to work with Mond gas. They were also the first to bring out a gas hammer for forging purposes. A description of this useful little instrument will be found in the 3rd edition, p. 94.

The **Fawcett** engine, brought out by Fawcett, Preston & Co., Liverpool, from the designs of Mr. Beechey, is no longer made. A trial was carried out by Mr. Miller in February, 1890.

Stockport.—As soon as the Otto patent expired, the Stockport firm, among others, adopted the Otto cycle for all classes of their engines, with various improvements in detail. In their latest motors all valves are of the mushroom type, and are worked by levers from cams on the auxiliary shaft, geared 2 to 1 to the crank shaft; the valve seats are cooled by water. Compressions up to 85 lbs. per square inch for coal gas, and 100 lbs. for power gas, are now used, and the combustion space or cylinder end is cast in one piece with the exhaust valve box. The gas valve is controlled by the ball governor, and the admission is cut off if the normal speed is exceeded. All engines are governed on the "hit-and-miss" principle. In larger motors, and in those intended for driving dynamos, the governor actuates a small bell crank lever below the gas valve spindle, and shifts it to one side, if the speed is too great; no gas then enters the cylinder during the cycle. In the smaller engines a very simple governor is used, consisting of a weight on a spring, moved by a vibrating lever. For the low-pressure starting gear the advantage is claimed that the engine itself performs the whole operation, as soon as the gas is turned on. The crank is first placed in position with the ignition tube open to the cylinder, and all other valves closed. The Bunsen burner is lit, and as soon as the ignition tube is red hot, gas is admitted through a small auxiliary valve, thrown out of gear by the first explosion. The gas drives out the air in the cylinder through the ignition tube, and when it is all expelled, and the gas begins to follow it, the heat of the tube fires the gas, the flame strikes back into the cylinder, an explosion occurs, and the engine begins to work. Larger engines are started by means of compressed air. The oil to lubricate the cylinder is contained in a tank above the crank, from whence it flows by gravity to the lubricating pipes. Continuous lubrication by the crank pin, as in the Tangye engine, is also used.

Ignition is by a metal tube with a timing valve. Large engines are fitted with a double ignition tube so that, if one gives way, the second may be put into action at once, without stopping the engine. The latest

types, especially engines driven with poor gas, are fitted with magneto-electric ignition. The spark is produced by a small machine worked from the valve shaft, a cam from which releases the magneto lever, breaks the contact between two spindles, and causes a spark. A modification of the scavenging principle is also employed, and although the exhaust pipe is not exceptionally long, the valves are so arranged that air alone enters

Fig. 56.—The Stockport Engine.

first, just before the charge is admitted, thus reducing the consumption of gas. The latest engines are made horizontal, single cylinder, single-acting, in sizes from 1½ to 150 B.H.P. (see Fig. 56), and run at 240 to 150 revolutions per minute, and at a maximum piston speed of 750 feet per minute. Above this size two cylinders are used, either tandem or side by side, up to 300 B.H.P. Messrs. Andrew also make portable engines from 4 to 15

B.H.P., and a small vertical type in two sizes, ½ and 5 B.H.P., running at 220 and 200 revolutions. The larger engines are driven with Dowson, Mond, or coke oven gas. They have supplied engines of 1,400 H.P. for electric generators, and nearly 1,000 H.P. to work with Mond gas. Some of their motors have been working continuously for months with coke oven gas.

In a 65 I.H.P. motor driving a corn mill near Tonbridge, the results of a test made with Dowson gas gave 0·93 lb. of fuel consumption per I.H.P. hour, or 1·16 lbs. per B.H.P. hour. A test was carried out in 1898 on an engine driven with Dowson gas at Portadown, in which the indicated H.P. was 52, and the mean consumption of best Welsh anthracite 0·78 lb. per I.H.P. hour, the speed being 134 revolutions per minute. In a 47 B.H.P. engine tested at Belfast the consumption was 16·83 cubic feet of lighting gas per B.H.P. hour. Another trial was carried out in 1898 at Dartford under ordinary working conditions on two Stockport engines of 85·5 B.H.P., fed with producer gas from a Paisley generator, in which the consumption of anthracite was 0·88 lb. per B.H.P. hour. A careful trial was made in June, 1901, by M. Mathot on a 63 B.H.P. single cylinder Stockport engine driven with Dowson gas. The consumption of Belgian anthracite was 1 lb. per B.H.P. hour, including the boiler, and the thermal efficiency 18·8 per cent. Another important series of trials was made in April, 1904, on two single-cylinder engines driven with Wilson gas, and developing a total of 217 B.H.P. The consumption of bituminous slack was 1·4 lbs. per B.H.P. hour. Details of both trials will be found in the Tables. All the power required for Messrs. Andrews' Works at Stockport is supplied by their own gas engines, which drive all the shafting (see on this subject Mr. Bellamy's paper, "Gas Engines as Motive Power in Engineering Works"). During nearly a quarter of a century the firm made about 8,000 motors, 2,000 of these being of the original type, and 3,000 Bisschop engines.

Acmé.—The first Acmé engine, patented by Messrs. M'Ghee, Burt & Co., showed a novel attempt to solve the problem of how to increase expansion of the explosive gases in proportion to admission and compression. In this engine there were two horizontal cylinders, two pistons, and two crank shafts connected by spur wheels in the proportion of 2 to 1. The cylinders were alongside each other, one being shorter and smaller than the other. While the piston of the larger cylinder made one stroke, the piston of the smaller made two, one crank and one shaft ran therefore at half as many revolutions as the other. The cylinder volumes and lengths of stroke also differed, and the cranks being at different angles the pistons did not work together. When the first or larger piston had completed the in or out stroke, the smaller second piston was about 45° behind. The cycle of operations was divided between the two cylinders. Hot-

tube ignition without a timing valve, and discharge of the gases of combustion both took place in the smaller cylinder, the piston of which uncovered these openings near the beginning and end of its out stroke. The firing of the charge and the exhaust were timed to occur when the first piston was at positions corresponding to the inner and outer dead points.

Several sizes of this engine were tested, both with full load and running light, by Professor Rowden, of Glasgow. In 1888 and 1889 he experimented upon 2 H.P. engines, running at 170 revolutions per minute. A trial at full power gave 3·14 B.H.P., and a corresponding consumption of 18·1 cubic feet of gas per hour.

A four-cycle type of this engine has been brought out, and is now made by the Acmé Engine Co., of Glasgow, in which the usual functions of admission, compression, ignition and expansion, and exhaust, are carried out in one horizontal cylinder. Gas and air are admitted through mushroom valves to the water-jacketed combustion chamber at the back of the cylinder. Both admission and exhaust valves are worked by cams from a side shaft geared in the usual way, and cooled with water. The governor acts on the "hit-and-miss" principle upon the gas valve, and regulates the consumption. Ignition is by hot tube heated by a Bunsen burner, and controlled by a timing valve. The engine is made horizontal, single cylinder, in sizes from 1½ to 100 B.H.P. The consumption in a 40 H.P. engine recently tested was 12·7 cubic feet per B.H.P. hour of Glasgow gas of 670 B.T.U. heating value. A new vertical compound engine, having three pistons in one cylinder, two of which are motor, while the third is driven by the pressure of the exhaust gases, is described in the *Electrical Times*, September 10, 1903, but does not appear to be yet working.

Fielding.—This engine, made by Messrs. Fielding & Platt, of Gloucester, is constructed on the principle of the Otto, and has the same four cycle, but the slide valve is replaced by simple mitre valves. Ignition is by a tube maintained at red heat by a Bunsen burner, but there is no timing valve to the smaller engines, though for larger sizes it has been found necessary. A timing valve is constructed to open the port leading to the hot ignition tube, at the exact moment when an explosion is required. Punctual ignition is a necessary feature of nearly all gas engine cycles. Some inventors, however, have succeeded in dispensing with the timing valve, and they maintain that, by varying the length of the ignition tube, and the distance from the red-hot metal to the motor cylinder, accurate ignition can be obtained. The gases do not reach this heated part of the tube until the end of the in stroke, when compression is greatest. Ignition at the dead point has been one of the main features of the gas engine theory since the time of Beau de

Rochas, and it may be doubted whether it is really so easily obtained as these inventors assert. The practice of dispensing with the timing valve is, however, sanctioned by no less an authority than Mr. Atkinson. It is more usual in oil than in gas engines.

In the latest large power Fielding & Platt engines the charge is fired by electricity. The organs of distribution and exhaust are driven, as in the Otto, from a side shaft worked by worm gear from the main shaft. The valves are opened by cams. Another cam actuates the governor, which is of the rotary ball type, and regulates the amount of the charge admitted in accordance with the speed. Large power engines are provided with a self-starter connected to the engine, into which air is compressed at a pressure of 60 lbs. per square inch. The ordinary ignition is then sufficient to procure a motor impulse, and this method is said to be powerful enough to start an engine with partial load on. A well designed horizontal type, indicating 100 H.P., has been brought out. There is one "mitre-seated" valve for admitting the charge and expelling the burnt products. A piston valve driven by an eccentric on the crank shaft opens communication between the inlet and exhaust cylinder ports and this valve, the rod of which is worked by a cam. Ignition is by hot tube, and there is a timing valve in this engine, acted on by the same eccentric as the piston valve. Both tube and timing valve are made in duplicate, an arrangement found in other large English engines. The timing cam can be adjusted by hand, and thus the moment of firing altered at will, while the engine is running. All these organs are contained in a valve chest at the side of the motor cylinder. The rotary ball governor, worked from the crank gear wheel, controls both the air and admission valves. The quality of the charge is varied in proportion to the speed, but there are no "cut-outs" or miss fires. Another method is to reduce the supply of air and gas simultaneously. Less of the charge enters the cylinder, compression is reduced, and the following explosion is weaker.

The latest type is a four-cylinder vertical engine giving two impulses per revolution, and developing 150 H.P. with producer gas, at a speed of 250 revolutions per minute. The mitre valves in this engine are driven from a horizontal cam shaft, the electric ignition is obtained from a smaller shaft driven from the vertical governor shaft, which times the moment when the spark is produced. The governor acts upon two small pistons, which throttle respectively the gas and air inlets, more or less, according to the load; the maximum variation of speed is said to be only 3 per cent. The speed and the time of ignition can be varied by a small thumb screw while the engine is running. It is started by compressed air introduced into one cylinder only, and the others receive their impulse from it. Fig. 57 gives a sectional elevation of the engine, showing the

oil bath in the base, into which the crank pin dips. The admission valve is seen at A and the exhaust valve at B, C is the starting valve for one cylinder out of the four, I the inlet to admit the air under pressure,

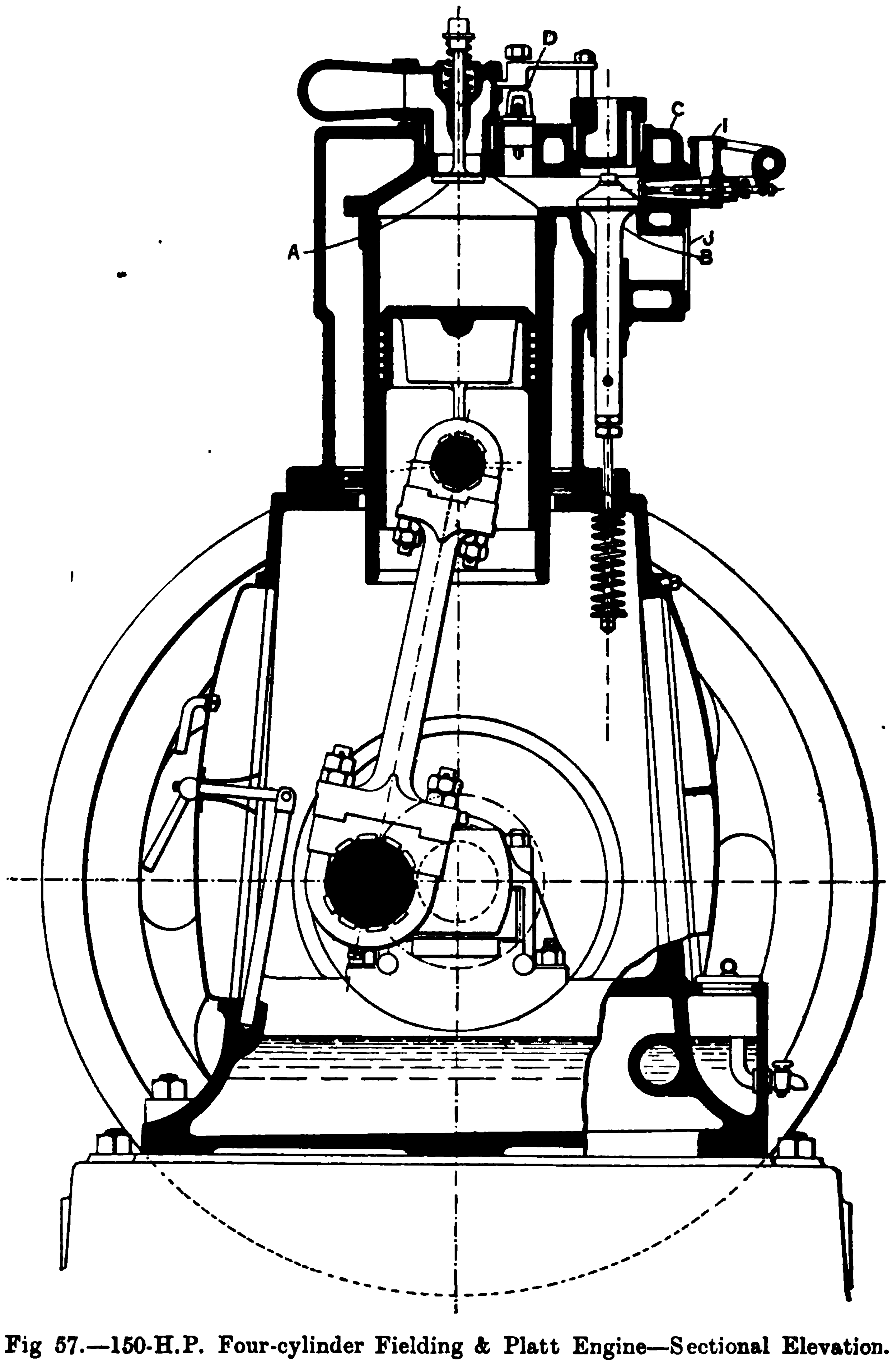


Fig 57.—150-H.P. Four-cylinder Fielding & Platt Engine—Sectional Elevation.

and J the rod working it. D is the electric ignition. Gas and air are admitted on the opposite side to the exhaust. The engine is made in sizes from 150 to 780 B.H.P.

Several large sizes of the Fielding and Platt engine were exhibited at the Royal Agricultural Society's Show at Doncaster in 1891, when it was brought to public notice for the first time. The makers claim a gas consumption of 15 to 20 cubic feet per H.P.-hour, according to the size of the engine and quality of gas used. The horizontal single-cylinder type is made from $1\frac{3}{4}$ to 125 B.H.P., and runs at 350 to 185 revolutions per minute. It is on a Fielding and Platt engine that experiments have been made by the Gas Engine Research Committee of the Institution of Mechanical Engineers, London. See Appendix A, Table 2, for details.

Premier. — Next to Messrs. Crossley, the Premier Gas Engine Company, of Sandiacre, near Nottingham, now make engines for larger powers than any other English firm, and their motors have been extensively adopted for use with producer, Mond, and blast-furnace gases. They were among the first to introduce the method of cooling the piston and valves, and by this means, and by a scavenger charge of air to cleanse the cylinder, with which all their engines are now provided, a mean pressure of 120 lbs. per square inch may be attained, without the danger of premature ignition. The Premier engine works on the four-cycle, with hot tube and a timing valve, and the side shaft is geared 2 to 1 to the main shaft in the usual way. In the smaller engines an inertia governor was formerly used, consisting of a bar with a weight at one end and a notched jaw at the other, working on to a lever opening the gas valve. The governor acted on a disc rotating at the same speed as the engine, and caused a pin upon it to miss the gas valve if the normal speed was exceeded. In the larger engines, especially those at high speed for electric lighting, the centrifugal governor is driven from the crank shaft, and acts by throttling the supply of gas. Thus the quality of the charge, the degree of compression, and the strength of the explosion are varied. Smaller engines are started by a pump which injects gas and air, while a catch holds the ignition valve closed. As soon as the mixture is sufficiently compressed by the pump, the timing valve is released while the engine is still at rest, the mixture enters the ignition tube, an explosion follows, and the engine begins to work. Engines for larger powers are started by compressed air, or by barring gear, which consists of a pinion gearing by means of a hand-wheel into teeth cast on the flywheel.

The Premier is made single-cylinder in sizes from 4 to 250 B.H.P., above that with two cylinders up to 1,200 H.P., and a piston speed of 750 feet per minute. All sizes are horizontal, the vertical type having now been discarded; engines for large powers have electric ignition, and

Fig. 58.—Premier 600-H.P. Scavenging Gas Engine.

are specially intended to work with producer gas. All engines are now constructed on the system of introducing a scavenger charge of pure air to cleanse the cylinder of the burnt products. In the single-cylinder, and in some types of the tandem two-cylinder engines, the air cylinder is formed by enlarging the front end of the motor cylinder. The working and air-pump pistons are bolted together, and form one piece of two different diameters. The smaller motor piston fits into the cylinder as usual; the larger, nearest the crank, works to and fro in an enlarged prolongation of the cylinder, forming a single-acting air pump. Into this a charge of pure air is drawn during the out stroke, and compressed by the next back stroke into a passage, from whence it enters the combustion chamber of the motor cylinder when the motor piston is halfway through the exhaust stroke, and drives out the products of combustion. The exhaust valve is kept open until after the crank has passed the dead point, and a free passage to the air is afforded. But as soon as the suction or admission stroke begins, the opening of the gas valve throttles the air ports, and less air is admitted to mix with the gas. Thus, a rich charge is obtained, undiluted by the burnt products, and a pressure of 120 lbs. per square inch is reached. In the latest types of tandem two-cylinder engines, the scavenging air cylinder is placed obliquely above the front motor cylinder, as seen at Fig. 58, and driven from the connecting-rod. Where two cylinders are placed side by side, the same valve shaft and set of cams may be utilised for both.

A large and important Premier gas engine plant was erected in 1896 at the Electrical Central Station of the Leyton District Council, and was tested by Professor Robinson in 1897. The gas for driving the engines was supplied by three Dowson generators, from a gasholder 20 feet in diameter and 10 feet high. The plant consists of four Premier engines, each driving a dynamo. The heating value of the Dowson gas was 156 B.T.U. per cubic foot, and the consumption of anthracite (not including the coke for the boiler) 0·84 lb. per I.H.P.-hour. During the trial each engine indicated 59·5 H.P., and gave with a dynamo 43·7 electrical H.P., making the electrical efficiency 73 per cent. An excellent trial on a 500-H.P. Premier engine of the scavenger type, and driven with Mond gas, in which the consumption was 60 cubic feet of gas, and thermal efficiency 25·6 per cent. per B.H.P., was made by Mr. Humphrey in July, 1900. Particulars will be found in the Tables. Of these engines 30 above 200 H.P. have been made, with a total of nearly 12,000 H.P., and they have supplied 13,750 H.P. to work with Mond gas alone. Premier gas engines have also been the first motors applied in England on a large scale to work with blast-furnace gases (see Chapter xii.).

Campbell.—The engine of this name, manufactured by the Campbell Gas Engine Company, Halifax, is another important four-cycle motor of

the Otto type, with hot-tube ignition, a timing valve, and ball governor. The cylinder, as in many other modern English gas engines, is fitted with a loose lining, which can be easily renewed. The engine is started by forcing a mixture of gas and air by hand into the cylinder, and the "Edmondson" starter is also sometimes used. It is made horizontal, with one or two cylinders, in sizes from 1 B.H.P. upwards, and vertical up to 300 and 400 B.H.P., with four cylinders; speed 250 to 160 revolutions per minute. The Campbell Gas Engine Company are

Fig. 59.—Sectional View, Westinghouse Engine.

among those English firms who have, of late years, made a special point of constructing large power engines to work with producer and other cheap power gases.

Westinghouse.—Although this engine was brought out by the Westinghouse Machine Company, of Pittsburg, and was thus originally of American construction, it has now, in the hands of the British Westinghouse Company, taken such a foremost place among British gas

engines that no account of them would be complete without a description of it. In size and importance it ranks among the leading types, and is probably made for larger powers than any other engine (1905). It has, from the first, been built on the lines of a first-class steam engine, for horse-powers from 250 to 1,500 and upwards, with two or more vertical cylinders, though the smallest size now made is 10 H.P. It is distinguished by its excellent design and careful workmanship. As it is intended, among other purposes, for driving dynamos, much attention has been paid to the governing gear; the "hit-and-miss" principle has been abandoned, and, by duplicating the cylinders, an impulse is obtained at every motor stroke.

Fig. 59 gives a sectional elevation of a Westinghouse engine. The crank and connecting-rod are in an enclosed chamber, and the latter is coupled direct to the plunger piston. This chamber is filled with oil, into which the connecting-rod dips at every revolution, and dashes an abundant supply of oil over all the internal working parts, no other lubrication being required for the cylinder and piston. A is the auxiliary shaft geared 2 to 1 to the main shaft, and carrying a cam which acts upon a roller just below the exhaust valve-rod E. This shaft is horizontal, and where there are two or more vertical cylinders placed side by side (the arrangement usually adopted), it carries a series of cams actuating successively the exhaust valve-rods of each cylinder. O is the exhaust passage, G is a guide lever, B is the admission cam shaft driven from the shaft A by bevel wheels through two smaller shafts, horizontal and vertical; on the latter is the ball governor. Air and gas enter at the side, and pass to the mixing chamber M. The two handles seen at L regulate the supply; the upper acts on the admission of gas, the lower controls the air valve. The mixture passes through N to the admission valve J, which is worked by the horizontal lever C and a cam on the shaft B. As the cam raises one end of this lever, the other is depressed, J descends, and the charge enters the cylinder. The sensitive governor acts by varying the quantity of the charge admitted to the mixing chamber M, according to the load. The proportions of gas and air are determined once for all, in conformity with the quality of the gas, by means of two indices at the top and bottom of the mixing chamber. The rotary ball governor is directly connected to the spindle of the vertical regulating valve, which works up and down in this chamber. As the balls move in and out, responding to the change of load, the valve increases or decreases the supply of the charge to the cylinder, and hence the force of the explosions; the quality does not vary, there are no miss-fires, and great regularity in running is said to be obtained. The shaft B carries a second cam actuating a horizontal rod through the guide D, which breaks the electric current at the wire S. In the larger

engines, the igniter F has two sets of terminals enclosed in one box. One of these only is used, the other is retained as a reserve, and thus the danger of a miss-fire or break is avoided. Starting, not a difficult process where two or more cylinders are used, is effected by compressed air, usually stored in tanks at a pressure of 250 lbs. per square inch. The admission valve in one of the motor cylinders is closed, the exhaust valve held open once in every revolution by a special cam. The starting valve, driven by a cam on the lower valve shaft, is then thrown on, connected to the air tank, and compressed air admitted to the cylinder at each down

Fig. 60.—Westinghouse Vertical 650 B.H.P. Three-Cylinder Gas Engine, with Direct-Driven Dynamo.

stroke of the piston. After a few impulses have been obtained in this way, energy is communicated to the other cylinders, and the engine is fairly started.

Fig. 60 gives a view of a 650 B.H.P. three-cylinder vertical engine of the same construction as that here described. The dynamo is on the crank shaft. Each cylinder is 25 inches diameter by 30 inches stroke, and the normal speed is 150 revolutions per minute. The same auxiliary and cam shafts serve the three cylinders. Where two cylinders are used a motor impulse is obtained at every revolution, and with three cylinders

at every two-thirds of a revolution ; in the latter type, which is the most usual, the cranks are set at an angle of 120° to each other. In all engines for large powers, the valves and pistons, as well as the cylinders, are water-jacketed.

Fig. 61.—Westinghouse Horizontal Double-Acting Engine.

Westinghouse gas engines are now built in sizes up to 2,500 H.P., and are much used to work with blast-furnace, coke-oven, Mond, and other cheap power gases, for all of which large engines are in increasing demand. Of sizes developing over 200 H.P., 45 engines have been constructed, with an aggregate of 17,600 H.P., or nearly 400 H.P. per engine, and over 7,000 H.P. have been supplied to work with Mond gas alone. The consumption is about 14 to 16 cubic feet of lighting gas per B.H.P. hour, or 1 lb. anthracite in a producer. This important and enterprising firm have not been behind others in adopting the double-acting type for large powers, and a two-cylinder engine of this kind, developing 1,500 B.H.P. has lately been brought out. It is made both vertical and horizontal; the latter type is shown at Fig. 61, coupled direct to an alternator. In construction it is similar to the single-acting engines, but the parts are in duplicate, as shown, and the charge is admitted and fired alternately at either end of the closed cylinder. In the vertical double-acting type, with two cylinders, the dynamo is placed on the crank shaft between them.

Forward.—This engine, made by the Forward Engineering Company (Kynoch), of Birmingham, is a simplified Otto. The Beau de Rochas cycle is used, but several improvements have been introduced. As in most modern English gas engines, ignition is by a hot porcelain tube. In the earlier engines the device for obtaining punctual ignition of the charge without a timing valve was ingenious. The opening of the tube was covered by a rotating disc, with "hit-and-miss" slots; the surface of the disc was divided into radiating sections, alternately pierced and solid, which, as the disc revolved, were brought successively across the ignition port. According to the section of the disc facing it, the ignition port communicated with, or was shut off from the cylinder. The governor regulated the speed of the engine by controlling the admission of gas and air into the combustion chamber, and also the rotary motion of the disc. If the normal speed was greatly exceeded, it also wholly cut off the gas supply. All the latest engines have a timing valve to determine the precise moment of ignition; the smaller sizes have a pendulum, and the larger a sensitive rotary governor, which acts on the "hit-and-miss" principle. They are fitted with a special starter, through which a minute quantity of light petrol is introduced into the cylinder; an explosion is produced, and an impulse communicated to the engine. It is made horizontal, single-cylinder, in sizes from 1 to 125 B.H.P., and runs at 550 to 160 revolutions per minute. The consumption of gas of 525 B.T.U. per cubic foot is said to be about 16½ cubic feet per B.H.P. hour.

Tests have been made on the Forward engine by Prof. Robert Smith and by Mr. Holroyd-Smith, and both these experts have reported favour-

ably. During trials of several hours the engine ran very steadily, and was found to work well, even under the severe test of counting the revolutions every ten seconds, instead of every minute, and varying the weight on the brake as rapidly as possible. The real test of regular working in an engine is absence of fluctuations in the speed when the load is suddenly put on or taken off, as in electric installations. In a test made by Prof. R. Smith at full load the speed was 177 revolutions per minute, with 59 explosions, or one in three. The consumption of Birmingham gas per I.H.P. per hour was 20·79 cubic feet, and 23·97 cubic feet per B.H.P. hour. The mechanical efficiency was 86 per cent. Another trial was made at the Birmingham Gas Works in 1894 on a 22·85 B.H.P. engine, in which the gas consumption was 21 cubic feet per B.H.P. and 17¾ cubic feet per I.H.P. hour. The mechanical efficiency was 84 per cent.

Midland.—The first engine of this name, manufactured by Messrs. John Taylor, of Nottingham, had two cylinders, motor and pump, both single-acting, and fixed upon the same frame. In the vertical type the two cylinders were side by side. The charge was admitted and compressed in the pump, and exploded, expanded, and discharged in the motor cylinder, thus giving an explosion every revolution. The admission valves were driven by an eccentric and rod on the main shaft, and the gas valve connected to a centrifugal governor. Ignition was by hot tube, without a timing valve, the length of the tube determining the moment of ignition.

Messrs. Taylor gave up the manufacture of this type, and, like many other firms, constructed engines exclusively on the four-cycle principle, single-cylinder, and chiefly horizontal. One small vertical type was made from 1 to 4 H.P. The horizontal engines ranged from ½ to 150 H.P., and were chiefly constructed with the cylinder supported on a cast-iron foot, but not overhanging. All the valves were worked by cams on a side shaft, driven 2 to 1 from the main shaft, and the gas supply was controlled by a ball governor. The smaller sizes had no timing valve; engines above 20 H.P. were fitted with a timing valve and starting apparatus. The Midland has been largely applied to drive dynamos, mills, pumping engines, &c., in England and abroad, and used with producer gas with good results. A test was made at Nottingham in 1897 on a 47 B.H.P. engine, driven with power gas made from coke, &c. The cylinder diameter was 16 inches with 21-inch stroke, and the engine ran at 218 revolutions per minute. The consumption of this poor fuel was 1·53 lbs. per B.H.P. hour; mechanical efficiency 81 per cent. Another trial was carried out at Worcester on a 70 B.H.P. motor driven by power gas from a Midland producer, and especially adapted for such work. The speed of the engine was 176 revolutions per minute; cylinder

diameter 19 inches, stroke 24 inches. There were no miss-fires. The mean pressure was 72·3 lbs., and the engine indicated 77 H.P. The consumption of cheap small anthracite was 0·65 lb. per I.H.P. hour. An engine of the same size at Nice consumed 17 cubic feet of town gas per B.H.P. hour. This engine is now made by the Railway and General Engineering Co., Nottingham, in sizes from 4 to 20 B.H.P.

Express.—The Express, made by Messrs. Furnival & Co., of Reddish, near Stockport, was another single cylinder gas engine which appeared after the expiration of the Otto patent. In design, construction, and cycle of operations it closely resembled it. Four engines, of sizes varying from 2 to 25 H.P., were shown at the Brussels Exhibition in 1897, but its manufacture has now been discontinued.

The same remark applies to the small single cylinder horizontal engine, formerly made by Mr. John Robson, of Shipley, on the Otto principle, which has disappeared from the market.

Trusty.—This engine, made by the Shillingford Engineering Co., of Cheltenham, is a well-constructed motor using the four-cycle, and having an explosion every two revolutions. The valves, of the mushroom type, are worked by a side shaft driven from the main shaft, the water-jacketed valve-box being placed at the side of the cylinder. Hot-tube ignition is used without a timing valve, the tube being made of a metal alloy. Governing is on the hit-and-miss principle, and the speed of the engine can be adjusted while at work. In some engines the governor consists simply of a weight attached to one arm of a lever swinging on a pivot, the other shorter arm of which opens the gas valve, unless the normal speed be exceeded. An 8 B.H.P. engine was tested at the Crystal Palace Exhibition in 1892, when the consumption of gas was 24 cubic feet per B.H.P., and 15·45 cubic feet per I.H.P. per hour. This engine is made horizontal, single cylinder, in sizes from ½ to 80 H.P., and runs at 180 to 300 revolutions per minute. A special feature claimed for it is that it can be converted into an oil engine, and *vice versâ*, without difficulty.

Robey.—This horizontal four-cycle engine is made by Messrs. Robey & Co., of Lincoln (Richardson and Norris patents), for driving dynamos for electric lighting, and other purposes. Coming from so well-known a firm, this motor seems to be well designed and constructed, and is already popular. It has heavy flywheels, and, as usual with this class of motor, the hit-and-miss centrifugal governor, driven from the cam shaft, is extremely sensitive; it acts on the gas valve in the smaller engines by means of a lever and small roller. In the larger, it carries a tripper blade, which engages with the end of the gas valve, and cuts off the supply if the speed is increased. Ignition is by a tube heated by a Bunsen burner; a double-headed valve, with two seats, is used to fire

the charge, and great accuracy of ignition is obtained. By a special arrangement the moment of ignition can be adjusted to suit the speed. The number of revolutions can also be readily altered, and the engine made to run, if required, at a low speed during the day and a higher speed at night. A patent "safety combination" is provided to prevent starting backwards, and by altering the eccentric lever the motion can be reversed, and the engine run in either direction in a few minutes. Engines above 9 H.P. are fitted with balanced cranks, and a Lanchester self-starter is used to start all sizes above 15 B.H.P. The Robey engine is made horizontal, single cylinder, single-acting, in sizes from 1½ to 40 B.H.P., and runs at 350 to 170 revolutions per minute, according to size. For electric lighting the speed is increased. The piston speed is about 600 feet per minute, and the consumption of lighting gas of 650 B.T.U. heating value is 14 cubic feet per B.H.P. hour. This engine can also be adapted to work with a suction gas plant.

National.—This engine, made by the National Gas Engine Co., of Ashton-under-Lyne, is another four-cycle motor of an improved Otto type, the manufacture of which has greatly developed within the last few years. The special features claimed for it are the strength of the crank shaft and working parts, and the care bestowed on their design for small as well as large power engines. The vertical centrifugal governor is on the side shaft. The porcelain ignition tube is placed at the side instead of the back of the engine, and is isolated from the metal holder in which it is fixed, an arrangement said to make it last longer, and to reduce considerably the consumption of gas for the burner. All motors, except the smallest sizes, have a timing valve. Engines worked with producer gas, and in general all for large powers, are fitted with electric ignition. The current for producing the spark is generated by a small magneto machine, the contact breaker being inside the cylinder. This gives a more certain ignition, especially where the quality of the gas varies, as with power gas. The crank pin is lubricated by a sight-feed oil cup fixed on the engine bed. A test made by Professor Robinson on a 25 B.H.P. engine showed a consumption of 16 cubic feet per B.H.P. hour, of gas having a heating value of 630 B.T.U. per cubic foot. In another trial of a 54 B.H.P. engine, the consumption of gas of the same quality was 15 cubic feet per B.H.P. hour.

A new type of engine with "super-compression" and a scavenger blast of air has lately been brought out, based on the principle of increasing the mean pressure in the cylinder, while reducing the temperature of ignition. As a rule, the temperatures developed in the cylinders of large power engines have so greatly increased with the compression of the charge, that water-jacketing, especially of the piston, is necessary. It is claimed for this new type, by no less an authority than Mr. Dugald

Fig. 62.—National Engine—Sectional View.

Clerk (who is now a director of the Company), that in it the thermal efficiency is raised, while the temperature in the cylinder is kept within such moderate limits that the engine works without water circulating through the piston.

A sectional view of a 250 B.H.P. engine is given at Fig. 62. The working parts, as shown, are the same as those of an ordinary four-cycle engine. While, however, the back end of the motor piston draws in, compresses, and exhausts the charge in the usual way, the front end is utilised as a pump, and sucks in at the same time a charge of air through a valve operated by a cam on the valve shaft. As the valve closes, the piston compresses the air into a reservoir forming a clearance space, and communicating with the admission end of the cylinder through ports. The pressure of air in the reservoir is about 16 lbs. per square inch. At the end of the charging stroke, the ports in the reservoir are over-run by the piston, and the air is drawn into the cylinder, raising the pressure of the charge by about 7 lbs. per square inch. The further motion of the piston closes the ports before all the air in the reservoir is exhausted.

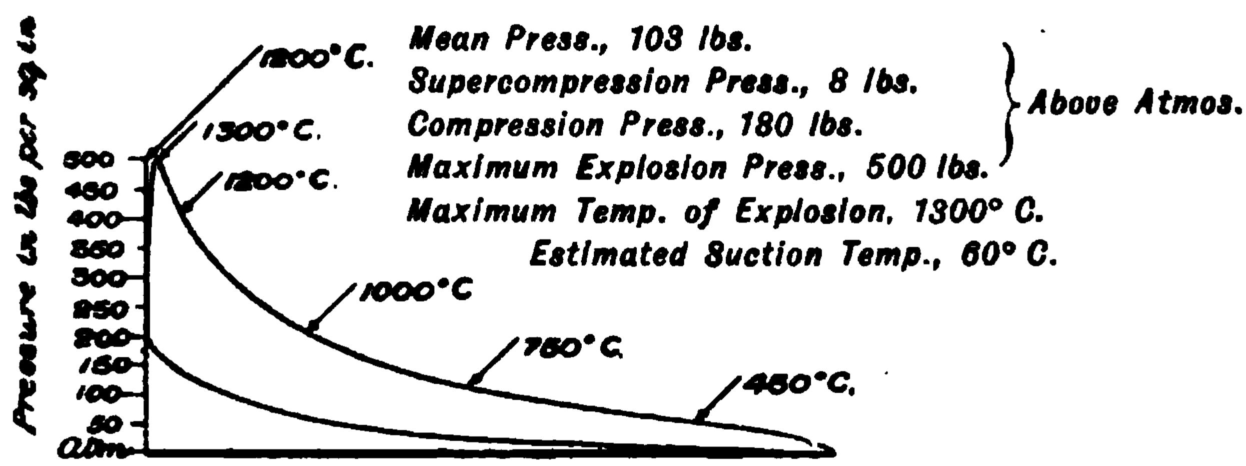


Fig. 63.—Diagram of National "Super-compression" Engine.
Mean Pressure 103 lbs. per sq. inch above atmos.

At the next return (exhaust) stroke, the piston again opens communication between the reservoir and the motor cylinder, and draws in the remainder of the slightly compressed air, which forms a scavenger charge, driving out the exhaust gases before it. Thus the air-admission valve is only opened once in every two revolutions, but the air under pressure is utilised at each revolution—during the first stroke to increase the compression of the charge, during the second to cleanse the cylinder of the burnt products. To prevent the charge of compressed air from increasing the temperature as well as the pressure in the cylinder, the reservoir is cooled with water. In this way, as shown in the diagram (Fig. 63), the mean pressure of the charge is raised to over 100 lbs. per square inch, while the pressure of compression is 180 lbs. per square inch. All engines above 250 H.P. are built on this principle of "super-compression." Fig. 64 gives an external view.

The National engine is made with one cylinder, horizontal only, from 2 to 160 H.P., to work with lighting gas, and runs at 500 to 160

Fig. 64.—350 H.P. National Gas Engine with Super-Compression—External View.

revolutions per minute, according to size, and for electric lighting, for the same powers, with slightly increased speeds. A horizontal twin-cylinder type is also made from 250 to 300 H.P. The output of this enterprising firm is one of the largest in England, and they claim to manufacture 180 engines per month.

The **Duplex,** also called the **Griffin,** and made by Messrs. Griffin, of Bath, is a small vertical four-cycle single-acting engine of rather novel design. It has two cylinders and two pistons working downwards on to the crank shaft through one crosshead and connecting-rod. The two parallel pistons are connected at their lower ends to a box crosshead, to which the connecting-rod is attached. Ignition is by incandescent tube, and the governor acts on the "hit-and-miss" principle on the single gas valve supplying both cylinders. The admission and exhaust valves at the top open directly into each cylinder, and are driven by a single cam from the valve shaft in the usual way. All the parts, cylinders, and covers are enclosed in one water jacket, the passages and chambers are kept cool, and a good thermal efficiency is said to be obtained. Ignition takes place alternately in either cylinder, with an impulse at every revolution. In an engine made for driving a dynamo, the diameter of each cylinder was 10¼ inches by 15 inches stroke, mechanical efficiency 86 per cent. When run at 180 revolutions per minute the engine developed 46 I.H.P., with a gas consumption of 18½ cubic feet per I.H.P. hour, and 40 B.H.P. with 21½ cubic feet of gas per B.H.P. hour. If driven at 200 revolutions per minute, the engine will give 80 I.H.P. Drawings and a description will be found in *Engineering*, May 20, 1898. This engine is now worked almost entirely with oil as a marine motor.

Clarke, Chapman & Co. (Butler's patent).—An engine has been brought out by this firm which, although not entirely new, since several foreign makers have utilised the idea with slight variations, does not seem to have been previously introduced into England. The usual ignition, admission, and exhaust valves have been replaced by a single circular rotary valve, worked by an auxiliary shaft geared to the crank shaft by worm wheels 4 to 1, thus rotating once every four revolutions or eight strokes. This slow motion is intended to prevent wear and tear, the various functions being carried out alternately on opposite sides of the piston valve. The revolving valve has two ports for the supply of gas and air, and two for exhaust, corresponding with the two passages to the cylinder. If hot-tube ignition is used, the circular valve also carries two ports for opening communication between the tube and the cylinder at the proper moment.

The gas and air are first admitted, the air through a nozzle, and the gas through a small screw regulating valve to an annular space round it, and thence to a mixing chamber beyond. This device is called the

inspirator. The charge then passes to a throttle valve controlled by the governor, as in a steam engine. It is admitted through the ports in the circular valve to the cylinder, and compressed, ignited, expanded, and discharged in the usual way. The makers prefer to ignite the charge electrically, and supply a coil and battery; a timing commutator is then fixed on the valve shaft. This method of ignition is said to facilitate starting, but if tube ignition be required, the hot tube is fixed immediately over the valve casing. There is no timing valve, explosion at the right moment being effected through the circular valve. The engine is regulated by a weight governor on the flywheel. If the normal speed is exceeded the weights fly out, and act through a shaft upon the throttle valve in the admission pipe, diminishing the quantity entering the cylinder more or less according to the excess of speed. The quality of

Fig. 65.—Clarke-Chapman Gas Engine—Single Cylinder. 1894-1899.

the charge is never varied, and as the governor does not interfere with the working of the circular valve, there is an explosion at every cycle, whatever the load. The pressure of admission is regulated by the governor, according to the work, the speed being kept practically the same. The engine is started by a small hand pump, which forces a properly proportioned mixture of gas and air into a chamber, from whence it passes through a valve into the cylinder, and is ignited either by the burner or, preferably, by electricity. An external view of the engine is shown at Fig 65, but its manufacture has now been discontinued.

A description of the Dawson high-speed four-cycle engine will be found at p. 107 of the Third Edition. It is no longer made.

Small Motors.—Of the numerous gas engines brought out within the last few years in England and abroad, many are made almost ex-

clusively for small powers. These little engines do not vary much in make, all being of the Otto four-cycle type; their main recommendation is not so much economy of gas as lightness, simplicity, and the ease with which they are started and worked. In many industrial operations the use of small gas motors often makes the difference between profit and loss to the employer, particularly with the difficulties of modern labour.

Gardner.—According to the makers of this engine, whose works are at Colne, in Lancashire, over 1,000 have been sold in five years. It is made four-cycle, single cylinder, single-acting, both horizontal and vertical, in sizes from ½ to 20 B.H.P. Hot-tube ignition, without a timing valve, is used for the smaller sizes; in the larger, electrical ignition has been successfully employed. The engines run at 450 to 190 revolutions, and have a piston speed of 300 feet per minute in the smallest to 500 feet in the larger sizes.

Roots.—In this engine, invented by Mr. Roots, the pressure of the exhaust gases was utilised to give a second working stroke. In other words, the engine was partly double-acting, having a motor impulse on either side of the piston, but combustion taking place on one side only. The usual operations were gone through on one side of the piston, and the exhaust gases then passed through ports to a space on the other side, containing compressed air, and acted on the piston to drive it back. This motor is no longer made; the Roots engine is now driven only with oil, and used in motor cars.

The **Dudbridge**, by Messrs. Humpidge & Holborow, Stroud, is a motor of the four-cycle Otto type, with one or two cylinders, presenting no novel features. The air and exhaust valves open directly into the cylinder without connecting ports, an arrangement said to reduce the amount of cooling surface affecting the incoming charge, and hence to give a better combustion. Ignition is by a metal tube heated by a ring burner, and there is no timing valve for sizes below 20 H.P. All engines are fitted with a self-starter, the larger sizes being started by compressed air. Lubrication is automatic, and the supply of oil is stopped if the engine is not running. The centrifugal governor acts on the "hit-and-miss" principle. The engine is made horizontal only, in sizes from ¾ to 110 B.H.P. with one cylinder, and up to 220 B.H.P. with two cylinders, and runs at 350 to 160 revolutions per minute. For driving dynamos the power is increased up to 250 B.H.P. with two cylinders, and the speed is greater. The power at the Dudbridge Iron Works is supplied by a gas producer on the Dowson system, fired with anthracite. Engines from 15 to 250 B.H.P. can be fitted with these "fuel-gas" plants. The consumption of lighting gas of 650 B.T.U. per cubic foot is said to be about 15½ cubic feet per B.H.P. hour.

The gas engine made by the **Newton Electrical Works**, Taunton,

is another of the usual four-cycle type, of simple design. Air is drawn in from the base of the engine, and both the gas and air valves are worked by one cam from the side shaft. The rotary ball governor acts upon the gas admission, and varies the supply of gas in proportion to the load. Ignition is by hot-tube ignition without a timing valve. The water-jacketed exhaust valve is driven by another cam on the side shaft. The engine is made horizontal only, in sizes from 2 to 34 B.H.P., and runs at 340 to 190 revolutions per minute.

Messrs. **Grice & Sons**, Birmingham, have brought out the "**Birmingham**" gas engine (Grice and Rollason's patents), a four-cycle, single cylinder, horizontal motor, specially intended to supply power for small industrial purposes, for which it is much in demand, such as printing, metal working, &c. The engine is very simple, with few parts; lift valves are used, with hot-tube ignition, and a rotary governor. It is made in sizes from 1 to 90 B.H.P., and runs at 250 to 150 revolutions per minute.

The **Globe**, made by Messrs. Pollock, White & Waddel, of Johnstone, near Glasgow, is an engine of the ordinary Otto type, with hot-tube ignition and mushroom valves, worked by cams from a side shaft driven in the usual way. The inertia governor acts on the gas-admission valve, and wholly cuts off the supply if the normal speed is exceeded. The engine is made horizontal only, single cylinder, single-acting, in sizes from 1 to 50 B.H.P., and the piston speed is about 500 feet per minute. It was exhibited at Brussels in 1897.

The **Ideal**, by Messrs Hardy & Padmore, of Worcester (Southall's patents), is a well-designed engine of the usual type, the admission and exhaust valves being at the back of the engine, and worked by cams on the side shaft, geared 2 to 1 to the main shaft. The "hit-and-miss" governor acts by cutting off the supply of gas if the normal speed is exceeded; air only is then drawn in by the piston, compressed, and discharged to atmosphere, till the speed has fallen. Ignition is by a hot tube, and a timing valve in the smallest sizes is dispensed with. The engine is made from 1 to 8 H.P. with a speed of 450 to 300 revolutions per minute.

A small engine of the same class is the **Drake**, made by Messrs. Drake & Fletcher, of Maidstone, and similar in type to their oil engine. It is built horizontal only, from 1 H.P. upwards, and runs at a somewhat high speed. The **Capell** (R. L. Capell, Northampton) and the **Smithfield** (Green & Sons, Blackfriars) are two small gas engines of the ordinary type; the latter is made from 1 to 20 H.P., and runs at 235 to 160 revolutions per minute.

A description of the **Edmondson** starter will be found at p. 110 of the Third Edition. Like the Lanchester, it is now seldom used, most

gas engine builders supplying their own starters, which chiefly consist of a reservoir of compressed air, with starting valve and connections.

Vogt.—This engine, designed by Messrs. Vogt and Recklinghausen, is at present in the experimental stage, but the principles it embodies and the working method are so novel that a brief description of it must be given. It is a double-acting engine, giving two impulses per revolution in one cylinder. The most striking peculiarity is that the explosions take place over water, with which the motor cylinder is filled, and neither a water jacket nor lubricating oil are required. The engine consists of a horizontal motor cylinder, with two vertical combustion chambers above it, one at either end. The cylinder is completely, and the combustion chambers partly, filled with water, which in the latter is maintained at a level varying with the pressure of explosion. The air, gas, and exhaust valves are all in the upper part of each combustion chamber, and, together with a water valve below the cylinder, are driven by eccentrics. Air and gas are supplied under pressure from pumps, the air pump being directly connected to the piston, and the gas pump driven slightly in advance, from the crank shaft.

The action of the engine is as follows:—Gas and air being compressed in the usual way in the combustion chamber at one end of the cylinder, are fired by electricity. The explosive pressure forces down the column of water below it, and the impact drives the motor piston to the other end of the cylinder, where the same action is repeated. Just before the end of this stroke the exhaust valve opens, the level of water sinks, uncovering the air valve, and the incoming air during the return stroke drives out the products of combustion. As the exhaust valve closes the gas valve opens, and the charge of gas and air is compressed and ignited as before. One of the characteristic features of the engine is the action of the governor on the water valve at the bottom, through which a little water is withdrawn at each stroke, a small quantity being injected to supply the deficiency. If the engine is running under a heavy load more water is withdrawn, the compression space is thus increased, and the governor at the same time closes the exhaust valve and opens the gas valve earlier in the stroke. More gas enters the cylinder, more air remains in it, and therefore the compression does not vary. If the engine is running light the process is reversed; less water escapes through the valve, the closing of the exhaust and opening of the gas valve are delayed, and both the compression space and volume of the charge are reduced. In this way the size of the compression chamber is varied, the degree of compression remaining constant. By adjusting the spring of the water relief valve, compression may be regulated to suit the load on the engine, and the quality of gas used. The electric igniter being almost at the top of the combustion chamber, the water does not

reach it and throw it out of gear. Both the air and gas may be stored, and delivered from an intermediate receiver, an arrangement also proposed in other motors.

The Vogt engine has at present been made only in a small $1\frac{3}{4}$ H.P. size, which was tested by Professor Capper and Mr. H. A. Humphrey. In the latter trial it gave a consumption of 16 to 18 cubic feet of lighting gas per B.H.P. hour, a remarkable result for so small an engine. An advantage claimed for it is that, if poor gas charged with a considerable amount of dust be used to drive it, the water would effectually clean the gas. The engine is started by compressed air.

CHAPTER VIII.

MODERN FRENCH GAS ENGINES.

CONTENTS.—Simplex—Delamare-Cockerill—Second Lenoir—Charon—Tenting—Niel — Letombe — Small French Engines — Brouhot — Bénier — Duplex—Gnome— Belgian Engines.

Simplex.—Among the various engines which have appeared to compete with the Otto, one of the best is the Simplex, brought out by MM. Delamare-Deboutteville and Malandin in 1884. The Deutz firm contended that their patent had been infringed, but the law suit which ensued was decided in favour of the Simplex. Although the Beau de Rochas cycle is used, the engine differs in the ignition and regulation of the speed, and the cycle is slightly modified. Ignition takes place when the piston has moved out a little, and not at the dead centre. The engine is horizontal, single-acting, and, till quite recently, single cylinder only in all sizes. In the Simplex cycle the usual sequence of operations is adhered to, giving one explosion for every two strokes forward and two strokes return, or one motor impulse in four. The compression space was from the first rather smaller, and the gases more highly compressed than in the Otto, and these high initial pressures and temperatures are a source of economy, because a poorer mixture can be used, and less gas is required. The charge is ignited electrically by a series of sparks. The piston, being allowed to move out a little before the explosion takes place, works more easily and quietly, and there is less shock to the bearings. Not only the pressure of the gases, but the pureness of the mixture is increased, and the products of combustion more completely expelled, because of the smaller space into which the charge is driven.

The system of electric ignition adopted by M. Delamare-Deboutteville obviates most of the attendant drawbacks, except that a battery and coil are required to generate the sparks. Of all the many devices hitherto resorted to for firing the explosive mixture, none of them can be called perfect. The plan originally adopted by Otto, of carrying a lighted flame to and fro in the slide valve, was open to many objections, and the great heat to which the slide valve was exposed soon deteriorated the quality of the iron, and made the joints shrink. Ignition by a hot tube has not these disadvantages, but firing by electricity has been universally adopted abroad. As employed by Lenoir and his successors, the system was

defective, and there were frequent miss-fires and premature ignitions, while sometimes no sparks were produced. In the Simplex, the ingenious

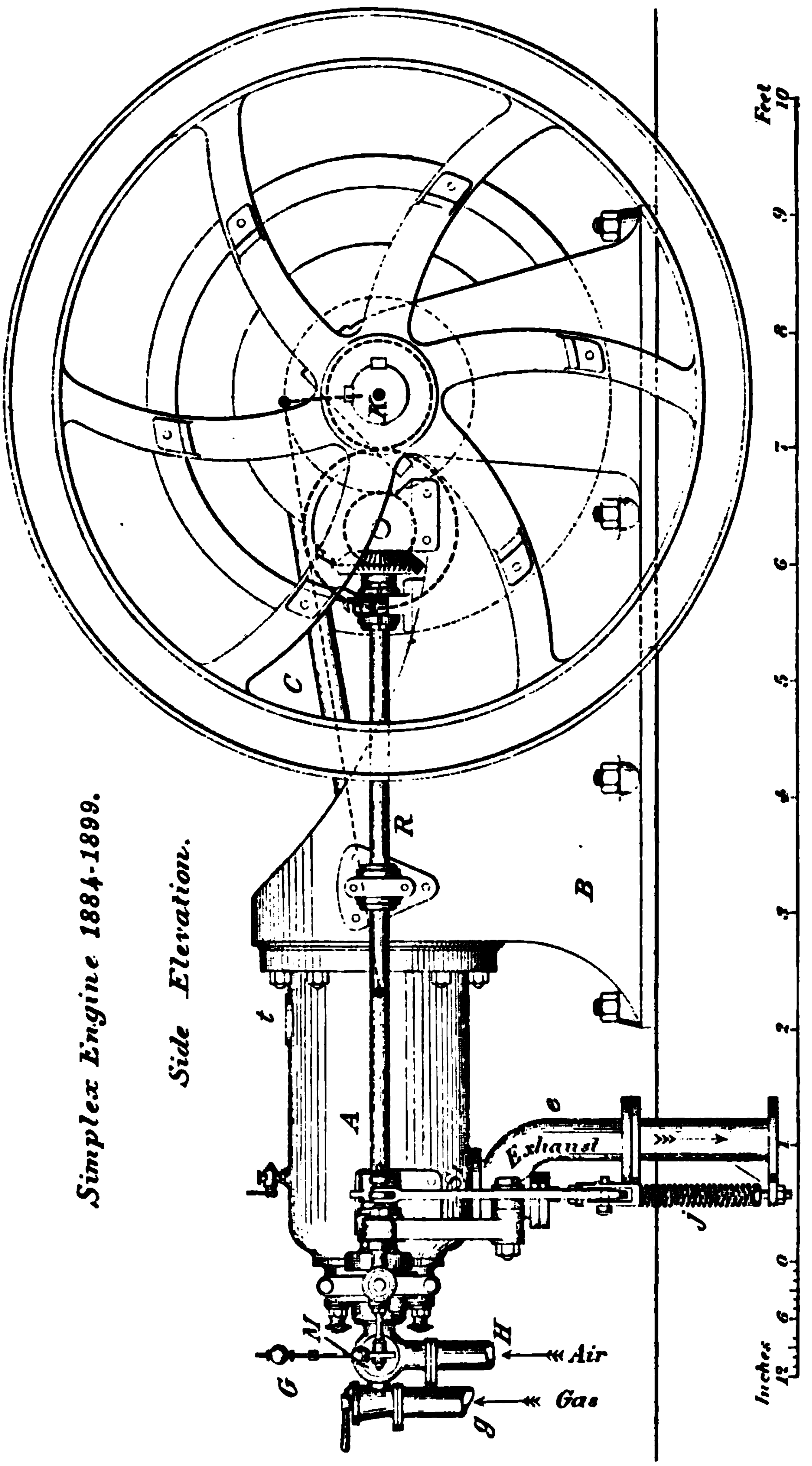


Fig. 66.—Simplex Engine—Side Elevation.

method has been adopted of introducing the two ends of the wires into an isolated chamber in the slide cover, and allowing a continuous stream

of sparks to play between them. A slide valve moves to and fro between the slide cover and the cylinder, at half the speed of the crank shaft. At a given moment, a zig-zag passage in the slide valve is brought opposite the ignition chamber, and opens communication between it and the admission port into the cylinder. Part of the charge, already highly compressed by the back stroke of the piston, rushes through the passage, is fired, and ignites the mixture in the cylinder. The moment of ignition, therefore, is regulated, not by the generation of the electric sparks, but by the movement of the slide and the edges of the port, and premature ignition cannot take place. This method of ignition requires a very pure explosive mixture. At the moment, therefore, when the com-

Fig. 67.—Simplex Engine.

pressed gases, driving before them the residuum of burnt products, pass from the cylinder into the slide valve, and just before the edges of the passage are brought opposite the firing chamber, a small hole opens communication with the outer air. The fresh mixture is at so high a pressure that all the burnt gases are instantly discharged through this opening, and the new charge is ready to be exploded.

Fig. 66 gives a side elevation, Fig. 67 a back view, and Fig. 68 a sectional plan of the Simplex engine. It has a single horizontal cylinder open at one end, working direct through a connecting-rod on to the crank, and a counter shaft driving the admission, distribution, ignition, and exhaust by worm gearing from the crank shaft. A is the motor cylinder,

P the piston, C the connecting-rod, and K the crank shaft. E and F are the wheels actuating the side shaft R, which makes one revolution for every two of the crank shaft. B is the base plate, M the mixing chamber

Fig. 68.—Simplex Engine—Sectional Plan. 1884-1889.

for the gas and air at the back of the cylinder, S the horizontal slide valve driven by the side shaft R; V and V′ are the flywheels, and U

and U′ the pulleys. The cylinder is cooled by a water jacket; the water enters at *t*, and is discharged at *t*′, Fig. 66. *e* is the exhaust

Fig. 69.—Simplex Engine—Sectional Plan of Admission Valves, Air Governor, &c. 1884-1889.

opening at the bottom of the cylinder, communicating with it through the valve S′. The air enters at H, the gas at *g*, through a pipe at right

angles to it. Both pass into the distributing chamber M, and from thence through slide valve S into the small chamber B′ in the rear of the cylinder, where they are compressed by the back stroke of the piston. In an engine of 6·7 B.H.P. tested with town gas by Professor Witz, the volume of the compression space was 32·4 per cent. of the total cylinder volume; with power gas it is only 25·6 per cent.

The side shaft terminates in a small crank *k* working the slide valve, and moving it once to and fro for every two revolutions of the crank shaft. The discharge pipe for the exhaust gases is seen at Fig. 66. The exhaust pipe *e* is closed by the valve S_1, held upon its seat by the spring *j*. At a given moment, a little before the end of the stroke, to avoid back pressure on the piston, a cam upon the side shaft R presses down one end of the lever L, the other end rises, releases the valve S_1 from the spring *j*, and pushes it up, and the exhaust gases pass out through *e*.

Fig. 69 shows a sectional plan of the organs of admission, distribution, ignition, and the air governor, all at the back of the cylinder. S is the slide valve, *k* the small crank on the counter shaft working it, and M the distribution chamber, with three openings, for the air at H, the gas admission at *g*, the valve of which is controlled by the air governor G; the third is the cylinder admission port, as shown by the arrows. At I is the ignition chamber, into which the ends of two electric wires surrounded by porcelain insulators are introduced, and a continuous stream of sparks plays between them. The slide valve has two openings, a rectangular passage *e*, in line with the cylinder port and distribution chamber, and an oblique opening *f*, which, as the slide moves to the right, brings the lighting chamber I into communication with the cylinder through the same port.

To regulate the speed, a sensitive air-barrel governor is used in some engines. If the speed be too great, the governor wholly cuts off the supply of gas, and admits air only for one or more revolutions. The slide valve S, Fig. 69, carries a small horizontal cylinder *c*, cast with it in one piece. The piston and rod of this cylinder are fixed to the slide cover, and the cylinder slides to and fro over them with the movement of the slide valve. At the opposite end of the cylinder *c* is a small opening *k′*, through which air is admitted and driven out by the piston at each forward movement of the slide, the quantity being regulated by a micrometer screw. At right angles to the cylinder *c* and the slide valve is a second smaller cylinder *n*, the piston-rod of which ends in a knife edge *o* fitting into the rod opening the gas valve. If the speed is normal, a cylinder-full of air is taken into and expelled from cylinder *c* at each to and fro movement of the slide valve, the piston of cylinder *n* does not move, and the knife edge *o* pushes the gas valve open. But if the speed be too great, more air is admitted into cylinder *c* than can be driven out

during one revolution, the pressure acting upon the piston in *n* drives it down, the knife *o* misses the edge of the gas valve-rod, and no gas is admitted.

In other engines a pendulum governor was formerly used, constructed on the principle of two pendulum weights, a lighter and a heavier, swinging on a fixed pivot at either end of a rod (see Fig. 67). The variation in the speed was obtained by a weighted knife-blade acting upon the gas valve. The lower heavier weight carried a notch, which at normal speed engaged with the knife-blade, and the gas valve was opened. If the speed of the engine was too great, the knife-blade was carried forward too soon, missed the notch, and the gas valve remained closed. A simple method of starting, by introducing the explosive mixture during the third or compression, instead of during the admission stroke, was patented by M. Delamare. The piston was stopped at the end of compression, and the compressed gases allowed to escape. The flywheel was then turned by hand, until the piston had moved through three-quarters of the stroke, and gas and air were admitted through a three-way cock to the cylinder. The movement of the flywheel was next reversed, the returning piston slightly compressed the charge, the electric current was switched on, and the engine fairly started.

The single cylinder 100 H.P. Simplex engine attracted much attention at the Paris Exhibition of 1889. The diameter of the cylinder was 23 inches, length of stroke 3 feet 2 inches, mean speed 100 revolutions per minute, and the initial pressure of the gases 6 atmospheres. For further particulars see Table of Trials.

The Lencauchez system of power gas has been adopted for driving larger engines, and several important plants, combining the Lencauchez generator and the Simplex engine, have been erected. One of these at the Pantin Flour Mills, near Paris, worked well for several years with gas supplied by two Lencauchez generators. During a long run test the indicated H.P. was about 280, brake power 220 H.P., mechanical efficiency 78 per cent. The consumption of non-bituminous Anzin coal (French) was 0·80 lb. per I.H.P., and 1·0 lb. per B.H.P. hour. The heating value of the gas was 152 B.T.U. per cubic foot.

Another plant at Aubervilliers, near Paris, consists of three Simplex 80 H.P. gas engines working a set of dynamos, which transmit power electrically to the different machines of some large chemical works. In a test made in 1894 the consumption was 1·4 lbs. of coal per B.H.P., and 1·1 lbs. per I.H.P. hour. At Étrepagny, in Eure (France), the town is lighted electrically by a 62 B.H.P. Simplex engine driven by Lencauchez gas. During a trial the consumption of French coal in the generator was 1·3 lbs. per B.H.P. hour. The water supplied to the town of Laval is also raised by pumps driven by an 80 H.P. Simplex engine worked with

generator gas. Most of the tests on these motors will be found in the Tables. Professor Witz's experiment on the 100 H.P. engine at the Paris Exhibition was one of the best. Fig. 70 shows an indicator diagram taken during the trial.

A new impetus has been given to the construction of the Simplex engine by the application of blast-furnace gases to drive it, at the large works of the Société Cockerill, at Seraing, in Belgium. The importance of the new industry, in which this distinguished firm have been pioneers, is shown in Chapter xii. They are now the makers of the Simplex, and to work it under these new conditions they have introduced various modifications. The engine has for some time been known as the "Delamare-Cockerill," or more briefly the "Cockerill." It has been adapted for very large powers, the shape of the cylinder head being, it is said, peculiarly well suited for use with producer and blast-furnace gases, which contain a certain quantity of dust. The method of electric ignition has been retained, and a "Bosch" electric apparatus is sometimes used. The valves are placed as far as possible from the cylinder, where the highest temperatures are developed, and the exhaust valve, the piston and piston-rod, as well as the cylinder and cover, are water jacketed. The

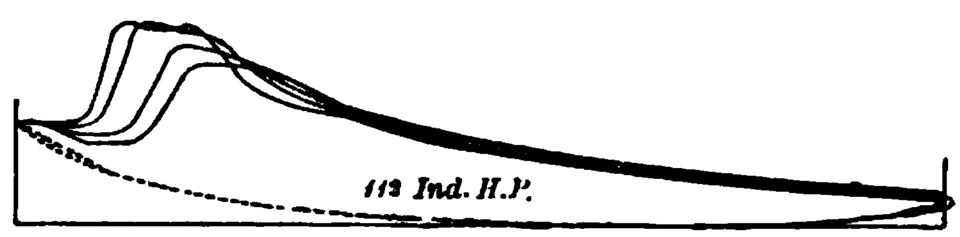


Fig. 70.—Simplex Engine—Indicator Diagram.

quantity of cooling water is said to be rather more than in other single-acting engines, to counteract the greater heat developed in the large cylinder. It varies from 13 gallons per H.P. hour in single-acting to 11 gallons in the double-acting engines, and the temperature of the water is raised from 60° F. to 120° F. A pressure of about 14 to 20 lbs. per square inch is required for the water to the valves and cylinder jacket, and of 55 to 70 lbs. for that to the piston and rod. The quantity of lubricating oil is from 1½ to 2 grammes per H.P. hour.

As soon as the engine was applied to large powers, a change in the method of governing became necessary. The 200 and 600 H.P. single-cylinder engines, mentioned at pp. 255, 256, are both governed on the original "hit-and-miss" principle by an air barrel governor, as described above. But when compression in motors driven with blast-furnace gases was increased to a maximum of 185 lbs. per square inch (13 atmospheres), this system was no longer applicable to single-cylinder engines, because of the great variations in the speed. The Cockerill firm, therefore, while retaining the air governor, decided to govern by varying the volume of the charge, its composition remaining constant. Air and gas are admitted into the combustion chamber through a vertical double-seated

valve, which is lifted for a shorter or longer time during the admission stroke, according to the load, and "variable admission" is thus obtained. The side shaft works a second shaft driving the governor, which consists of a small cylinder in which two vertical pistons move in opposite directions. The lower is connected to the engine, and rises more or less according to the speed. The air between it and the upper piston can only escape through an orifice of given size. If therefore the speed is increased, the pressure of the air drives up the upper piston, and a catch connected to the admission valve is released, by means of a series of levers and rollers. The valve is closed earlier in the suction stroke, and a smaller portion of the charge thus enters the cylinder. This method is suited to single-cylinder, or side-by-side engines, but not for tandem engines, of which the Cockerill firm now build many. In the latest types a rotary ball governor is used, and the admission, air, and gas valves are all placed one above the other at the top of the cylinder. The admission valve, carrying the air valve with it, is worked by levers and a cam on the auxiliary shaft, and closed by a spring; the gas valve immediately above it is driven by a separate lever. A catch worked from the cam shaft holds the gas valve lever stationary, while the admission and air valves descend. At a given moment of the stroke, the governor releases the catch, and gas enters the mixing chamber. Thus if the speed be too great, air alone is first admitted and less gas afterwards, but as it enters near the ignition port the charge will always ignite, to whatever extent the governor may diminish the quantity of gas per stroke. Some of the large Cockerill engines are now started by compressed air, but in general this firm prefer to use a small benzine "Longuemare" carburator for the purpose. The flywheel is turned by an electric motor, and the explosion is produced by admitting carburetted air behind the piston.

The Seraing firm are almost alone among builders of large gas engines in retaining the single-cylinder type for powers up to 600 H.P., and they have constructed one engine single-acting, developing above 700 H.P. in a single cylinder. In view of the large powers now and probably in the future required for gas engines, they maintain that if, as in Deutz engines, the power in each cylinder is limited to 250 H.P., the number of cylinders, in engines developing 2,500 H.P. and upwards, will be inconveniently increased. Where great regularity in running is not required, as in blowing engines, they advocate the use of one cylinder, but two or more cylinders, giving at least one impulse per revolution, are desirable for driving dynamos. Like most of the chief firms they have brought out a double-acting type, in which the four-cycle is carried out on either face of the piston, in a cylinder closed at both ends. By this means the power developed in each cylinder is doubled, but as the two motor impulses succeed each other during one revolution, the engine doing

Fig. 72.—Blast-furnace Gas Engines at Seraing.

***In front*—One Tandem Double-acting 1,500 B.H.P. Engine.** ***At back*—Two Tandem Single-acting 700 B.H.P. Engines.**

Fig. 71.—Richardson & Westgarth Cockerill Engines worked with Coke-oven Gas.

Fig. 72.—Blast-furnace Gas Engines at Seraing.

In front—One Tandem Double-acting 1,500 B H.P. Engine. *At back*—Two Tandem Single-acting 700 B.H.P. Engines.

only negative work during the next, perfect regularity in running is not obtained. This is a defect inherent in all double-acting four-cycle engines.

The Cockerill firm make single-cylinder engines, as described; engines with two cylinders, either side by side or tandem, up to 1,250 H.P., and a double tandem type with four cylinders and two motor impulses per revolution. These arrangements are duplicated in the double-acting type, developing powers up to 5,000 and 6,000 H.P. As a rule, the Cockerill engines require from 10,300 to 11,000 B.T.U. per B.H.P. hour. The consumption, therefore, with blast-furnace gases having a heating value of 100 B.T.U. per cubic foot would be about 103 to 110 cubic feet, and about 70 cubic feet of producer gas of 156 to 168 B.T.U. per cubic foot.

The manufacture of the Cockerill engines has now been acquired for England by Messrs. Richardson & Westgarth, of Middlesbrough, who make them of the type already described, governing by variation in the volume of gas admitted, with constant compression. They have constructed a plant, shown at Fig. 71, to work with coke-oven gases, the largest installation of its kind at present in England; and have supplied an 800 H.P. single-cylinder engine to drive the blowing engines at Sir A. Hickman's Works, Bilston. They claim to be builders of the largest gas engines in England, and have in hand or already constructed twelve single-cylinder engines of powers varying from 250 to 800 H.P., and three tandem double-acting, developing 500 and 750 H.P.

The Cockerill engines are made in France by the Creusot firm; in Austria by Breitfeld & Dánek, of Prague; and in Germany by the Markische Maschinen-Bau Anstalt, Wetter. The Seraing and affiliated firms have already built 126 engines, with an aggregate of nearly 100,000 H.P., the bulk of which are worked with blast-furnace gases. Fig. 72 gives a view of the Central Electric Station at Seraing, consisting of three Cockerill engines, all driven with blast-furnace gases. In the foreground is a tandem double-acting 1,500 H.P. engine, with 3 feet 3 inches cylinder diameter, and 3 feet 7 inches stroke; speed, 100 revolutions per minute. Behind are two single-acting tandem engines, developing 700 H.P. Diameter of cylinders, 3 feet; stroke, 3 feet 3 inches; number of revolutions, 135. These engines were started in February, 1904.

Second Lenoir.—Since the introduction of his first motor in 1860, Lenoir, the pioneer of gas engines, had been incessantly working to perfect his invention and to remedy its defects, especially the large consumption of gas. Sixteen years later, in 1876, a new direction was given to the efforts of mechanical engineers by the appearance of the Otto, and Lenoir, abandoning the lines on which he had formerly worked, introduced, in 1883, an engine in which the Beau de Rochas cycle was closely followed. This engine has one motor impulse in four. The charge is fired electrically, and the piston moves out so little during

explosion, that ignition practically takes place at constant volume. The cylinder is divided into two parts, the water-jacketed motor cylinder, in

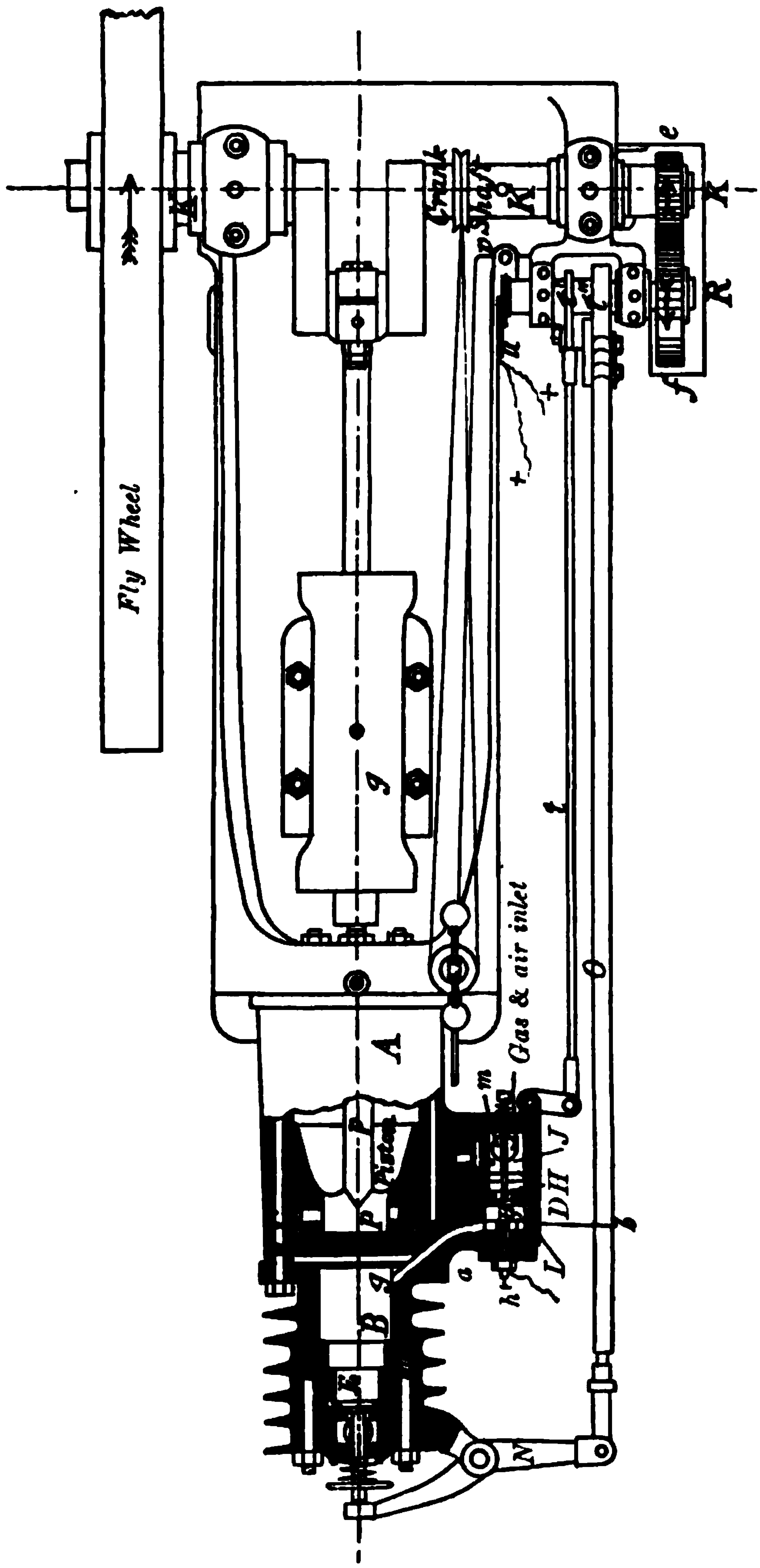


Fig. 73.—Second Lenoir Gas Engine—Sectional Plan.

which the piston works, and the compression chamber, which is cooled only by air in contact with radiating cast-iron ribs. The incoming gases,

as they pass through this chamber, are heated prior to ignition, their pressure is thus increased, and although a poor and greatly diluted mixture is used they ignite easily. The motor is not made in large sizes.

Fig. 73 gives a sectional plan of the engine. A is the motor cylinder, with piston P, B the compression chamber surrounded by external ribs, E is the opening for the exhaust at the further end of the compression chamber, D the valve chest at the side of the cylinder, containing chambers for the admission, mixing, and ignition of the charge. A portion of the piston-rod is seen at *p*, working through the connecting-rod and a strong cylindrical guide *g* on to the crank shaft K. The various organs are worked by a counter shaft R, driven from the main shaft by two spur wheels *e* and *f*, in the proportion of 2 to 1. Upon it are two cams t' and t'', and a projection *v*. The exhaust E is opened by the lever N and the rod O from the cam t''. The valve chest D is divided into J the admission, and I the mixing and ignition chambers, with valve H between them. The air enters from below at *m*, and the gas from above; the governor acts upon the gas admission pipe. The cam t' admits the gas, and the charge passes through the channel *g* into the cylinder, and is fired electrically at *h*. Contact is established or interrupted by the projection *v* on the counter shaft R, which at a given moment in the cycle of the engine closes the circuit, and produces the spark. The passage *g* is always open to the cylinder, but the charge cannot ignite until the maximum pressure is reached. For starting, the valve shaft carries a second smaller cam, opening the exhaust valve during the compression stroke.

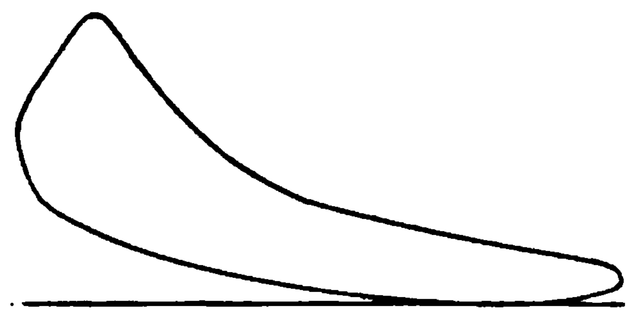


Fig. 74.—Second Lenoir Engine—Indicator Diagram.

M. Tresca, who had been the first to experiment upon the original Lenoir motor, made trials upon the modern engine, in which the consumption was 24 cubic feet of gas per I.H.P. per hour. The indicator diagram is shown at Fig. 74. In a 16 H.P. engine the consumption of Paris gas per B.H.P. per hour was a little over 21 cubic feet.

Charon.—This engine was patented in 1888, and shown in the French section of the Paris Exhibition in 1889. It is a horizontal four-cycle motor, resembling the Otto in outward appearance and mechanical details, with lift valves and electric ignition. To obtain greater expansion in proportion to admission and compression of the charge, a novel feature has been introduced in the construction of this engine. The student will already be familiar with various devices of this kind, but the method employed by M. Charon, although complicated, is original and ingenious, and gives a real economy in the consumption of gas.

The engine has two valves, one to admit gas alone, the other for the admission of the charge of gas and air to the cylinder. In the latter valve the air enters centrally from below, and the gas circumferentially through a number of small holes immediately below the valve seat. When the piston has reached the end of the first out stroke, with the full charge of gas and air behind it, the gas valve closes, but the admission valve remains open during the first part of the return stroke. This valve communicates through a pipe with a spiral coil in a cylindrical chamber shown to the left in the drawing, Fig. 75. At the top of the latter the air enters, and is drawn through the spiral coil before it

Fig. 75.—Charon Gas Engine.

passes to the admission valve. As this valve does not close at once, a portion of the gases, instead of being compressed in the cylinder, passes into the spiral passage, driving out the air in the latter. The valve then closes, and during the remainder of the stroke the charge is compressed by the piston in the usual way, ignited, expanded, and discharged. When the cycle recommences, the admission valve again opens as well as the gas valve, and part of the gases stored up from the previous charge are first drawn in, then air from the atmosphere through the chamber. The next compression stroke refills the spiral coil.

The usual operations are effected by lift valves worked by cams on a side shaft. There are four cams, actuating respectively the gas valve, the valve admitting the charge to the cylinder, the ignition and exhaust. The electric wires are carried into a small chamber at the back of the cylinder, immediately above the admission valve. Contact is interrupted by a lever moved by a cam on the side shaft, and the spark is produced just before the crank reaches the inner dead point. Great care is taken

in this engine to determine the precise moment of ignition. The speed is ingeniously regulated in the following way:—The ball governor acts not only on the gas cam, but upon the cam opening the admission. Both cams are slightly conical. If the normal speed is exceeded, the governor alters the position of the cones horizontally on the side shaft, the effect being that the gas valve is opened for a shorter, the admission valve for a longer, period. The greater the excess of speed, the longer the latter is kept open. More of the gas and air pass into the spiral coil, less are retained to be compressed in the cylinder, and the charge will be poorer in quality and less in quantity, until the speed is reduced within normal limits. In this way the strength of the explosion, the expansion of the charge, and the compression are varied by the governor, in accordance with the work done, but no ignitions are missed. The exhaust is similar to that of the Otto engine.

The difficult problem of varying the compression and expansion of the charge seems in this engine to have been ingeniously treated, and the

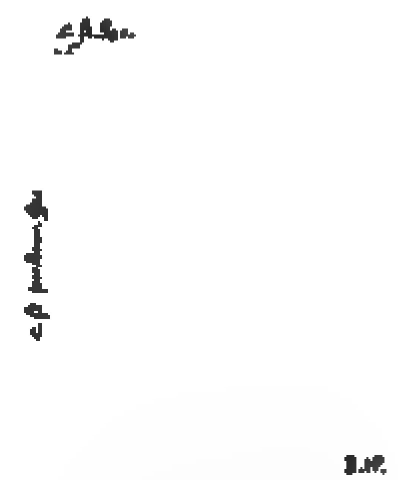


Fig. 76.—Charon Gas Engine—Varying mechanical efficiencies according to power, on same engine.

Fig. 77.—Charon Gas Engine—Varying consumption of gas according to power, on same engine.

makers claim a considerable economy of gas. A trial by Witz in 1895 on a 60 B.H.P. engine showed a consumption per hour per B.H.P. of 16 cubic feet of lighting gas, having a heating value of 588 B.T.U. per cubic foot. For details see Table. In a 60 H.P. engine officially tested at Bordeaux in 1897, the consumption was the same. M. Rateau made a trial on a 50 B.H.P. engine at St. Étienne, in which 16·6 cubic feet of gas were used per B.H.P. hour. A series of trials upon a 50 H.P. Charon engine were also carried out by MM. Cuinat and Allaire in 1894. The engine had two cylinders, each 13·7 inches diameter, and 23·6 inches stroke, and ran at 150 revolutions per minute. The novelty of these experiments was that fifteen separate trials were made at powers rising by degrees from $16\frac{1}{3}$ B.H.P. up to a maximum of 53 B.H.P, and for each power a corresponding indicator diagram was taken. These successive

diagrams showed that when the engine was worked at a power much below normal, the explosion line was almost horizontal; in other words, combustion of the charge took place. As the weight on the brake increased, the line rose until at the maximum power it became vertical, proving that explosion was almost at constant volume. The sixteen indicator diagrams are given in the original report. The following diagram, Fig. 76, shows the varying mechanical efficiencies, according to the power on the engine. It will be seen that the efficiencies rise in a regular curve in accordance with the work done. With $16\frac{1}{3}$ B.H.P. developed on the brake, the mechanical efficiency was 52 per cent., and rose to 91 per cent. at 53 B.H.P. The next diagram, Fig. 77, gives the curve of varying consumption of gas, according to the B.H.P. upon the engine. At $16\frac{1}{3}$ B.H.P. this consumption was 38 cubic feet per B.H.P. hour, at $24\frac{1}{3}$ B.H.P. it was $26\frac{1}{2}$ cubic feet, and at 53 B.H.P. it was 17 cubic feet per B.H.P. hour, being $2\frac{1}{2}$ times higher with the minimum than with the maximum power developed on the brake.

An interesting application of these engines to electric lighting has been made at the National Printing Office in Paris by the Société des Industries Économiques, the makers of the Charon. Till within the last few years this large establishment, with a staff of 1,800 workmen, was lighted by gas. The building is old, but electric light, though urgently needed, could not be installed, it was said, on account of the expense. Some years ago the Société des Industries Économiques undertook at their own cost to set up a complete plant of engines driving dynamos. They agreed to supply electric light throughout the printing office for thirteen years at a lower cost than was formerly paid for gas, and at the end of that time the whole installation is to become the property of the Government. The plant comprises four Charon engines of 45 H.P., and four dynamos, supplying 2,500 electric lamps at present, but the number can be increased to 3,000 for the same power. The dynamos are driven by straps from the engines, which are worked by town gas, and run always at full load. The price now paid for lighting is the same as formerly, with double the light, and the Société will be able to cover their original outlay and make a good profit before the expiration of their term. A complete account of this development, with drawings, will be found in Witz, vol. iii., p. 435.

The Charon engine is made horizontal, single cylinder, from 1 to 100 H.P., and with two cylinders side by side from 25 to 200 H.P., and runs at 270 to 150 revolutions per minute. A small vertical single-cylinder type has been introduced, in sizes from $1\frac{1}{3}$ to 4 H.P., running at 270 to 240 revolutions per minute. About 1,500 of these engines have been made in France in nine years.

The **Tenting** is a horizontal, single cylinder, single-acting engine,

using the Beau de Rochas cycle. It presents no remarkable features, but is simple in construction, and has been adapted for propelling carriages. The various types of the **Ravel** engine are now no longer made. M. Ravel introduced a new type in 1888, drawings of which will be found in Witz and Chauveau, but its construction has now been given up. A few **Forest** engines are worked with gas, but they are now mostly driven with oil, for motor cars and marine work. One was exhibited at Paris in 1889.*

Niel.—The Niel, which first appeared at the Paris Exhibition of 1889, is a horizontal engine of the Otto type, with several ingenious modifications. The exhaust is a vertical lift valve; the admission gear is worked from a side shaft geared to the main shaft by worm wheels. In the original type this valve shaft actuated a conical revolving valve, with two apertures for the admission and ignition of the charge. Air was admitted from a reservoir, or through the base of the engine. By the rotary motion of the valve the charge was drawn into the cylinder through one of the ports, and to diminish the shock admission lasted only during two-thirds of the stroke, the charge expanding slightly during the last third. This is shown in the indicator diagram, Fig. 79, where the initial pressure of the gas and air falls slightly below that of the atmosphere. At the end of the return stroke the conical valve opened communication through the other port with the hot ignition tube. A thin metallic diaphragm in this conical valve, acted upon by the pressure of the gas in the cylinder, prevented leakage while the charge was fired. The oscillating governor consisted of a T-shaped, three-armed lever, driven from an eccentric on the crank shaft. If the speed became too great, the arm opening the gas valve was displaced, and no gas admitted. The engine was started by compressing a charge of gas and air by hand into a reservoir. Communication was then opened with the motor cylinder, and the products of combustion in the latter were expelled by the fresh compressed mixture. Drawings of this engine, and a description by M. Moreau, will be found in the *Comptes Rendus de la Société des Ingénieurs Civils*, October, 1891.

A new type of the Niel engine has lately been brought out, in which compression pressures of 140 to 170 lbs. per square inch are realised. As seen at Fig 78, the exhaust valve is below the cylinder, and driven from a cam on the side shaft. The cooling water is admitted at the bottom, close to the exhaust valve and combustion chamber, where the temperature is highest and circulates first round the valve, being discharged at the top. The exhaust opens when the crank is 50° behind the dead point, the temperature in the front part of the cylinder is therefore not so high as at the back, and the water jacket is here made smaller. The governor acts on the gas and admission valves, and through them on

* For descriptions see the earlier editions of this book.

the air supply, but the "hit-and-miss" principle has been abandoned. As in other modern motors, these valves are arranged vertically, one above the other, at the top of the cylinder. The section of the gas valve

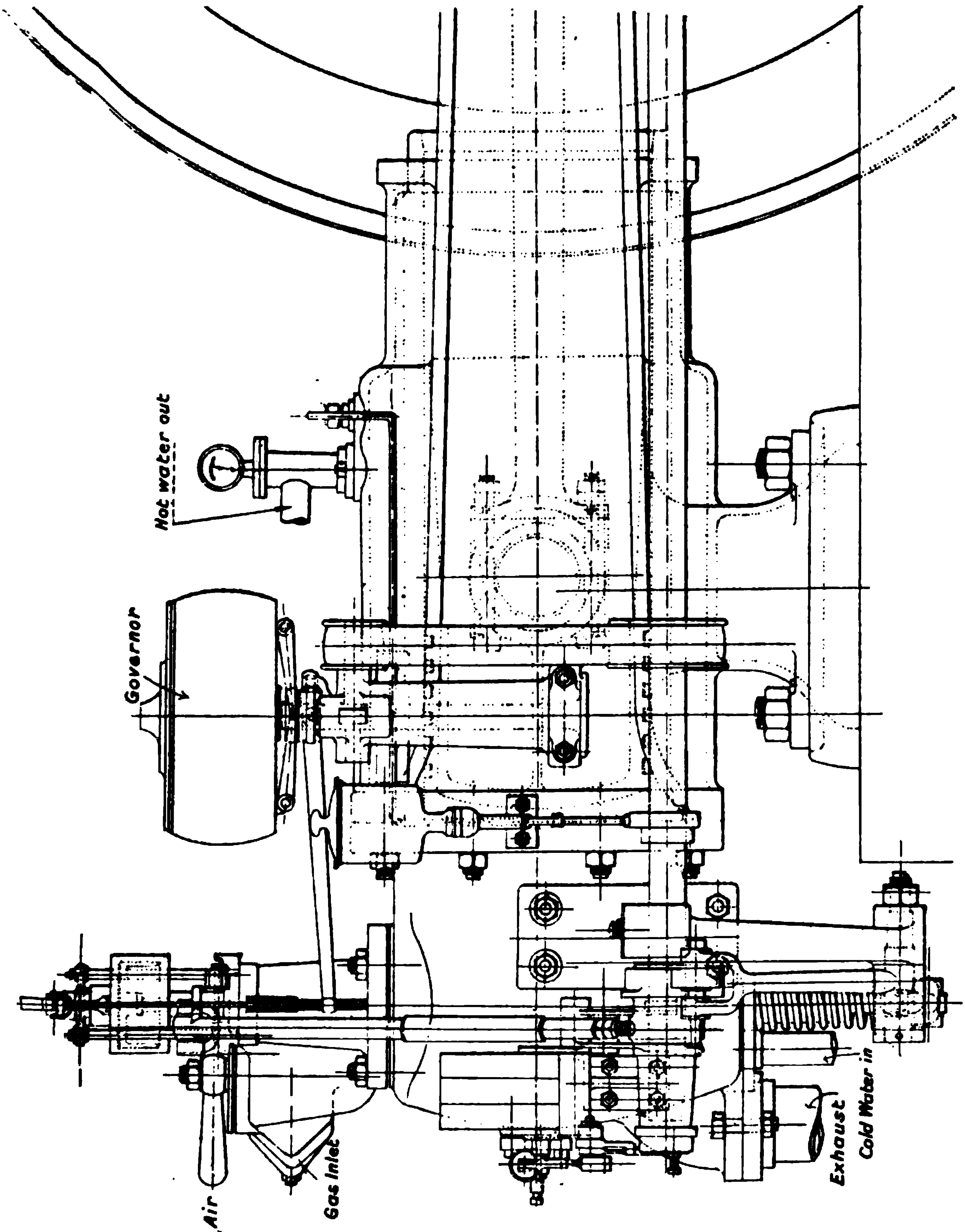


Fig. 78.—Niel Engine—Sectional Elevation.

is varied according to the calorific value of the gas used, and by adjusting the opening of the valve the engine can be run with any kind of explosive gas. The air enters at right angles to the gas, through a

narrow opening which imparts a certain speed to it, and thorough mixing of the charge is said to be obtained.

The stem of the admission valve passes through the hollow stem of the gas valve, both being held on their seat by a spring, and worked through two levers from a cam on the valve shaft. The action of the lower lever, opening the gas valve, does not vary; the movement of the upper is regulated by the governor. Under normal conditions the gas and admission valves open together, and the required amount of air is drawn in between them. At the top of the valve stem is a small "dash-pot," consisting of an air cylinder and piston. If the load varies, the governor acts by obstructing the passage of air to the dash-pot cylinder, a partial vacuum is thus formed in it, the piston and the valve stem cannot act, and the admission valve is only slightly opened. Less of the charge passes to the cylinder, and compression is diminished. In this way the speed of the engine and number of impulses are maintained constant, but the strength of the impulse per stroke is reduced. As, how-

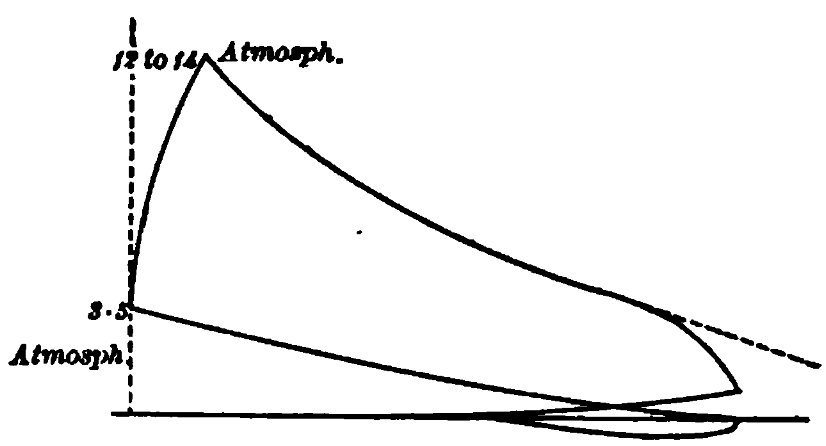


Fig. 79.—Niel Engine—Indicator Diagram. 1891.

ever, the opening of the gas valve does not vary, the same quantity of gas is always drawn in, but a smaller quantity of air; the charge is richer, certain ignition is obtained at all loads, and the engine is said to run with great regularity. The crank and connecting-rod have centrifugal lubrication, and oil under pressure is sent to the piston and cylinder. Ignition is by a magneto-electric machine, producing sparks at a very high temperature, and the moment of ignition may be varied according to the speed and quality of the gas used. It is the variation in the compression, which ranges from 50 to 150 lbs. per square inch, and thus the degree of intensity of the explosion, which forms a special feature of this engine.

Trials.—Experiments upon a 4 H.P. Niel engine were made by M. Moreau in 1891. Fig. 79 gives an indicator diagram taken during the trial. At a speed of 160 revolutions per minute, with a maximum pressure of 12 to 14 atmospheres, the mean consumption of Paris gas was 27·2 cubic feet per hour per B.H.P. The mechanical efficiency was 75 to 80 per cent. A trial made by MM. Witz and Moreau in November, 1901, showed a consumption of 15·3 cubic feet per B.H.P. hour of lighting gas

of 634 B.T.U. per cubic foot. The heat efficiency per B.H.P. was 25·5 per cent. Particulars will be found in the Tables.*

The Niel has proved one of the most successful of French motors. A large number of these engines are now at work in France and elsewhere, and 130, for powers of from ½ to 25 H.P., are said to have been sold in nine months. They are made horizontal only, with one or two cylinders, in sizes from 1 to 200 B.H.P., and run at 230 to 150 revolutions per minute. The Compagnie des Moteurs Niel, at Paris, have lately taken up the generation of poor gas on the Taylor system, for driving their larger motors. The gas producer is made in France by MM. Fichet and Heurtey, and is described at p. 223. A test in 1896 on a 22 I.H.P. engine driven with this gas showed a consumption of 1·7 lbs. coke per I.H.P. hour. Niel engines of 56 H.P. are also worked with Fichet and Heurtey gas at Eu in France. At the Electrical Station at Rheims, the power is furnished by three Niel gas engines, two of 80 H.P., with two cylinders side by side, their cranks being at an angle of 180°; the third is of 85 H.P. At Calais, the electric light station is provided with two 85 H.P. Niel engines, each with two cylinders side by side, and at Cognac and at Royan there are similar gas plants.

Letombe.—This engine, one of the largest and most important of French motors, is made by the Compagnie de Fives-Lille, at Lille, and by the Société des Moteurs Letombe, at Paris. It is a four-cycle, single- or double-acting engine, with variable compression and expansion. The charge is fired electrically, and the exhaust port below the cylinder is uncovered by the piston at the end of the stroke, and worked by cams from the valve shaft in the usual way. The novelty of the engine is that the volume of the charge admitted is independent of the stroke, and the quantity is increased by the action of the governor as the quality diminishes. In the engine as at first made, this effect was produced by slide valves, with ports adjusted to vary the time during which they established communication between the mixing chamber and the motor cylinder. Drawings of this type are given by Witz. In the later type the same result is obtained by means of two vertical valves; one, the ordinary admission valve, which remains open during the whole of the first forward stroke, while the other valve, which is connected to it by a chamber, carries the gas valve immediately above it; between them is the passage for the admission of air. The lift of this double valve depends on the ball governor acting on a finely graduated cam on the valve shaft. This cam is made with two sets of gradations; one set acts

* A novel method by M. Ringelmann of determining and representing graphically the consumption in a gas engine, as a function of the power developed, with special application to the Niel engine, will be found in the *Bulletin de la Société des Ingénieurs Civils*, August, 1902.

on the admission of gas, the other, in inverse ratio, on the quantity of the charge passing through the lower valve to the ordinary admission valve, and so to the cylinder. As the governor rises, the cam is shifted, and the longer the step brought into play for opening the lower valve and drawing in the air, the shorter is that acting on the gas valve. In the latest engines the gas and air valves are separated, and the three valves—for gas, air, and admission—are placed side by side, and worked by separate cams on the valve shaft. The stepped cam for admission of air is acted on by the governor, and, according to the greater or less amount of air admitted and the corresponding vacuum produced in the admission chamber, more or less gas is drawn in.

Fig. 80.—Letombe Gas Engine—Double-acting.

By this ingenious arrangement the quantity of the charge entering the cylinder is made independent of the amount of gas. The higher the speed of the engine, the less gas enters, but more of the total mixture of gas and air; that is, the quantity of air is increased as that of the gas diminishes. The volume of the mixture being thus larger, and the compression space the same, its compression pressure is increased and ignition is always obtained, however poor the charge. In other words, instead of reducing the area of the indicator diagram by reducing the height of the pressure of explosion, M. Letombe diminishes it by lengthening the lines of admission and compression. The degree of the latter, or maximum lbs. on the compression line ("super-compression"), varies with the amount of gas and air to be compressed. The inventor claims to reduce the area of work on the indicator diagram while actually

increasing the thermal efficiency. If the load is greatly reduced, the supply of gas is wholly cut off, the energy stored up in the flywheel sufficing to maintain a regular speed for a time.

This interesting engine was from the first made double- as well as single-acting. Fig. 80 shows the 50 H.P. double-acting engine exhibited at Brussels in 1897, where it attracted much attention. Double-acting engines are sometimes started by pumping a small quantity of gas by hand into one side of the cylinder, while an explosive charge is sent into the other. The electric current is applied, and an explosion is produced strong enough not only to start the engine, but to compress the charge on the other face and to throw the starting gear automatically out of play. The engine is also so arranged that it stops of itself at the right point in the stroke. Some engines are started by compressed air, one face of the piston being utilised to compress the air into a reservoir. One admission of air is said to be sufficient to start the largest engine. Lubrication is provided by oil under pressure from a small pump, and in all engines above 200 H.P. the pistons are cooled by water.

The double-acting engine led to the adoption of the latest, or "Mono-triplex," type, formed by substituting for the long guide required to take the double-acting piston a second single-acting cylinder, which occupies no more space than the guide, and serves the same purpose of supporting the piston. By the addition of this single-acting to the double-acting cylinder, M. Letombe obtains three motor strokes in two revolutions, and claims to develop 50 per cent. more power without any increase in the space occupied. In an engine developing 400 H.P., the cylinder diameter was only 3·28 feet. A further advantage is that the engine can, by adjusting the cams, be worked single-, double-, or treble-acting. Two double-acting cylinders may also be conjoined for powers from 500 to 1,500 H.P. The engines are made specially for use with producer or blast-furnace gases. Many have already been constructed, including sixteen for powers above 200 H.P., with a total of 4,400 H.P. One of the most important installations is at Valenciennes, where four 200 H.P. mono-triplex Letombe engines driven with poor gas from two Letombe producers (see p. 230) have been working successfully since 1901. This plant was tested by Professor Witz in July, 1903. The consumption of Anzin anthracite was 0·8 lb. per B.H.P., and the heating value of the gas produced 147 B.T.U. per cubic foot. Particulars will be found in the Tables. In a smaller 20 H.P. engine, also worked with poor gas, the consumption was just under 1 lb. coal per B.H.P. hour. Letombe engines and generators are also working at Toulouse, Lille, and elsewhere in France. They are made single-acting from 7 to 28 B.H.P., double-acting and "mono-triplex" from 27 to 360 B.H.P., and run at 280 to 140 revolutions per minute.

Several small French engines have dropped out of public notice, and are no longer made. Among these are the **Pelloree**, the **Perrin**, the **Crouan**, constructed by the Société Française du Gazomoteur, and the **Durand**; all are for very small powers, and of the ordinary four-cycle Otto type. The **Delahaye** is now worked only with oil, and is chiefly used to drive motor cars. The same remarks apply to the **Roger**, made by M. Roger, of Paris, patentee of the Benz engine in France, who brought out a small vertical gas engine of the Otto type, with hot-tube ignition and centrifugal governor. The interest of this firm has now been transferred to M. Serpollet, the well-known maker of steam motor cars.

Brouhot.—The engine made by Brouhot & Cie., at Vierzon (Cher), is especially intended for agricultural purposes, such as making wine, distilleries, breweries, saw, flour, and other mills, and for electric lighting; it may be driven either by gas or petroleum. It is of the ordinary four-cycle type, with a valve shaft driven by wheels from the crank shaft. The charge is fired by an electric spark from a small battery, or from a magnetiser. Gas and air are admitted into an external mixing chamber through apertures, the orifices of which are exactly proportioned. The ball governor acts upon the openings, and varies the quantity of the charge without altering its quality. The engine is made horizontal in sizes from 1 to 25 H.P. single cylinder, and 10 to 30 H.P. for two cylinders, and vertical from 1 to 4 H.P. For very small powers the latter are preferable, because they occupy less space. It can also be adapted for use with poor gas. Several hundreds of these engines are at work.

The **Otto** engine, made in France by the Compagnie Française des Moteurs à Gaz, is described in Chapter vi.

Bénier.—One of the latest developments in gas engines is the introduction of suction gas producers attached to the motor, the gas being made per stroke and passing direct to the engine, without intermediate storage in a gasholder. The idea is not new; the Gardie gas plant, described in former editions of this book, was brought out several years ago in France, but was not successful. The Bénier is an interesting typical example, which, for a time, met with some favour. The success of the suction gas producers now made by most of the leading English and Continental firms (see p. 202) shows that Bénier's plant was designed on the right lines. According to a German authority, the failure of his generator was due to its combination with a gas engine, the type of which was not suited for work with a suction producer.

The generator, which is an improvement on the Arbos system, is connected to a two-cycle gas motor, and the gas is produced automatically per stroke as required, by the suction of the motor piston. The gas

producer consists of a cylindrical chamber lined with fire-brick, and surrounded by an outer casing and an inner annular space. The anthracite or coke falls through a horizontal slide valve on to the hollow revolving circular grate, which makes one-quarter of a revolution per hour. Steam, generated in the grate itself from a stream of water constantly passing over the bars, is mixed with air, and the two are drawn by the suction stroke of the motor piston to the grate, through the annular space between the furnace and the outer casing, and superheated. The gases from the furnace are passed through a washer, and thence to the motor cylinder. The engine has two parallel cylinders, motor and pump, in which the usual working method in the two-cycle type is carried out. The pump piston draws the gas through the generator, and air from the atmosphere, and sends them on to the motor cylinder. The exhaust is in front, the holes being uncovered by the motor piston, near the end of the explosion stroke, and closed on its return. During the last period of the pump stroke a small quantity of air is drawn in, and delivered first into the motor cylinder, to prevent the escape of the fresh charge through the exhaust. The charge is fired electrically.

Two trials of a Bénier gazogene motor were made by Professor Witz at Lille in 1894. In the first, English anthracite was used, the calorific value of which was taken at 14,400 T.U. per lb., and the consumption was 1·5 lbs. per B.H.P. hour. The second trial was made with broken gas coke, the heating value of which was estimated at 12,240 T.U., and the consumption was 1·6 lbs. per B.H.P. hour. Heat efficiency about 12 per cent. For further particulars, see Table of Trials.

The **Compagnie Parisienne au Gaz,** who are the makers of the modern Lenoir, brought out a useful engine of their own design some years ago. It is a compact and handy motor of the ordinary four-cycle type. The exhaust and gas valves are worked by cams on the side shaft driven 2 to 1 from the crank shaft, the automatic air valve is lifted by the suction of the piston. Ignition is by electricity, the spark being produced by a contact maker on the side shaft connected to the ignition chamber. The centrifugal governor acts upon the conical cam regulating the gas admission valve, and more or less gas is admitted according to the speed. To start the engine there is an additional cam on the valve shaft, acting on the exhaust valve during the compression stroke. The consumption of lighting gas is said to be from 19·4 to 24 cubic feet per B.H.P. hour.

The **Duplex,** made by the company of that name at Paris in sizes from 1½ to 80 B.H.P., horizontal only, is an ordinary four-cycle motor, with a speed of 450 to 160 revolutions per minute. Ignition is by hot tube in engines up to 20 H.P., above that size the charge is fired by an electric spark. The ball governor acts upon the gas, and regulates the

supply according to the power required. Small sizes of this engine are much used in various industrial trades in France, and it is also made up to 250 H.P. to work with producer gas. A 150 H.P. plant is working at the La Touche mines, Ile-et-Vilaine. A new double-acting type, with an impulse at every revolution, was brought out in 1896, and described by Witz, vol. iii., p. 292, but it does not seem to have made much progress. The valves for the admission of gas and air are at one end only of the cylinder, and the mixture is conveyed to either side as required, through a passage below, but admission lasts only during half a stroke, and is then cut off by the piston.

A description of three small engines, the **Champion,** made by MM. Caloin & Marc, of Lille, the **Regent,** by Béhu, of Paris, and the **Noël,** by Fritscher & Houdry, of Provins, will be found at p. 129 of the third edition of this book. The last was one of the earliest gas motors produced in France. None of them seem to have held their ground against the keen competition to which all gas engine makers are now exposed, and they have practically disappeared from the market.

The **Gnome,** made by Thevenin, Frères, and by Séguin, of Gennevilliers, is a form of the Seck, a German engine described at p. 185, and is chiefly worked with oil. When made as a gas engine, the gas valve is placed below the air valve on the same spindle, and forms with it a double-seated automatic valve. There is no cam shaft, the exhaust valve alone being mechanically driven from an eccentric on the crank shaft. Ignition of the charge, lubrication, and governing on the "hit-and-miss" system, are the same as in the Seck oil engine. By the French firms it is made in sizes from 1½ to 22 B.H.P., with a speed of 400 to 250 revolutions per minute.

Belgian Engines.—Practically all gas engines now made in Belgium are of the Otto four-cycle type. The following list of the chief makers has been kindly supplied by a distinguished firm of Belgian Engineers:—Ragot, Daelstorm, Nagel & Hermann, Société Belge des Moteurs à Gaz et à Pétrole, Société Économique, H. Bollinckx, all at Brussels; Allard Frères, Société des Forges et Usines de Gilly, Société Anonyme des Haies, Veuve Michel, B. Lebrun, in Hainault; Fétu, Defise et Cie., Société des Moteurs à Grande Vitesse, and Longdoz, all at Liège; Société Phœnix at Ghent, and J. Gilain at Tirlemont. For the important developments of the Simplex engine by the Société Cockerill at Seraing, near Liège, see p. 136.

CHAPTER IX.

GERMAN GAS ENGINES.

CONTENTS.—Koerting—Siegener Maschinen-Bau Gesellschaft—Vereinigte Maschinen Fabrik Augsburg and Maschinen-Bau Gesellschaft Nuremberg—Soest—Dingler — Oechelhaueser — Borsig — Adam — Güldner — Benz — Daimler — Dürkopp — Dresdener Gas Motor — Kappel — Lützky — Sombart — Capitaine — Berlin-Anhaltische — Bechstein — Langensiepen — Gnome — Austrian Engines—Bánki— Swiss Engines — Schweizerische Maschinen - Fabrik, Winterthur — Martini — Escher-Wyss.

Koerting.—Next to the Otto, no gas engine is so extensively made in Germany as the Koerting. It was first brought out as a vertical motor in 1879, and may therefore claim to rank as an historical engine. Since then many improvements have been introduced, and the mechanical details are continually undergoing change. MM. Koerting are among the foremost makers of large engines, and have of late years devoted special attention to the construction of engines for very high powers, to work with producer, blast-furnace, coke-oven, and other poor gases. The success which has attended the introduction of their two-cycle double-acting motor may be said to mark an epoch in gas-engine construction.

In the original engine brought out by MM. Koerting and Lieckfeldt a method of ignition by propagation of flame in a conical tube was adopted, but in all the present engines ignition is by electricity, except in horizontal motors below 10 H.P., in which hot-tube ignition is still used. The method of regulating the speed was, at the time of its introduction, a novelty. If the normal number of revolutions was exceeded, the governor acted upon a lever, one end of which kept the exhaust valve open, while the other held a return valve in the mixing chamber closed. As the gas and air were admitted through an automatic valve lifted by the vacuum in the cylinder, no charge could enter while the exhaust was open.

There have been several distinct periods in the construction of the Koerting-Lieckfeldt engine. In the type of 1881, to which a return with important modifications has lately been made, an auxiliary pump was introduced; the four operations of admission, compression, explosion plus expansion, and exhaust were divided, as in the Clerk engine, between two cylinders, and an impulse was obtained at each revolution. The cylinders were vertical, and there were two cranks, motor and pump, working upwards on to the same crank shaft. If the speed was too

great the ball governor opened communication between the pump and a reservoir, into which part of the compressed mixture was driven. Draw-

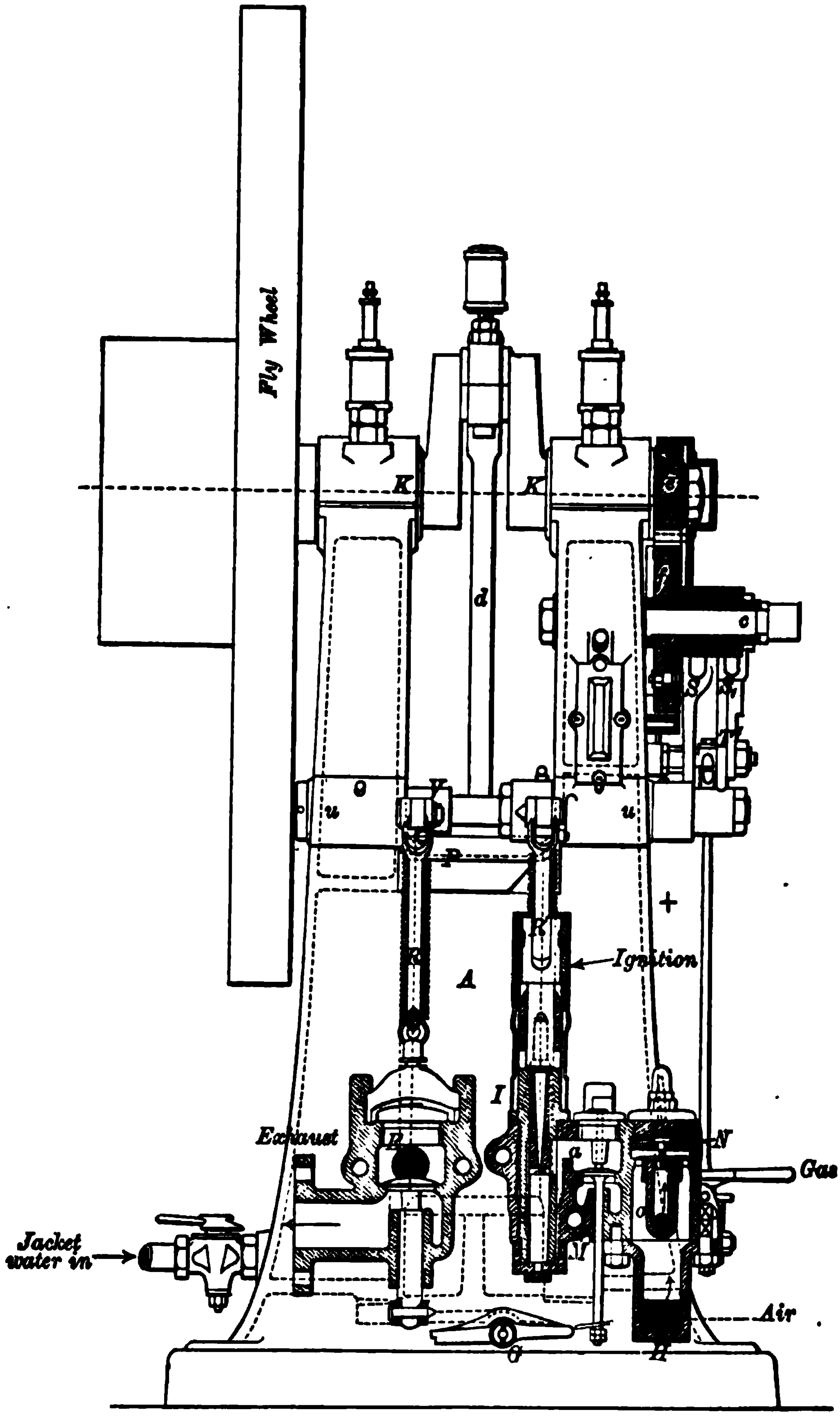


Fig. 81.—Koerting Gas Engine—Sectional Elevation. 1888-1899.

ings of this engine will be found in Schöttler. The firm has long been known as Koerting Bros., of Hanover, and the engine as the Koerting.

Type of 1888.—In this vertical motor, of which Fig. 81 gives a

sectional elevation, the four-cycle of Beau de Rochas was adopted, giving one working stroke in four. A is the motor cylinder, P the piston, *d* the

Fig. 82.—Koerting Four-cycle Horizontal Engine. 1905.

connecting-rod working direct on to the crank shaft K. All the valves, with the exception of the automatic admission valve, are worked from a rocking shaft *u*, driven 2 to 1 from the crank shaft; *o* is the mixing chamber, N the admission, and M the charging valve. Ignition was originally by an external flame through a groove, and the governor acted on the exhaust valve, as already described, on the "hit-and-miss" principle. This method of regulating the speed has now been given up in all the Koerting engines. For a full description of this vertical type see Third Edition, p. 135.

Horizontal Type.—This is the construction Messrs. Koerting have now adopted for all their motors, except a small vertical engine lately brought out for marine work and motor cars. In the earliest type ignition was by a hot tube open to the cylinder, a special arrangement being made to prevent premature ignition. There were three valves—the automatic gas and air valve, the admission valve to the cylinder, and the exhaust. The two latter were driven by eccentrics on the crank shaft, and a lever acted on by the governor worked between them. A description of the method used to prevent the eccentrics from opening the valves at every revolution, instead of every other revolution, is given by Schöttler (third edition).

Fig. 82 shows the latest type of the Koerting four-cycle horizontal engine, up to 150 H.P. There are three valves, the admission and exhaust, driven by cams from an auxiliary shaft geared to the crank shaft, as shown, and the double-seated mixing valve, opened by the suction of the piston. Air enters through the lower, and gas through the upper seat of this valve, through a number of fine jets, to ensure the thorough mixing of the charge, on which great stress is laid in all the Koerting engines. The stroke of the valve is always the same, therefore the proportions of gas and air do not vary. The governor acts upon a throttle valve placed between the mixing and the admission or inlet valve. The lift of the latter is constant, but the governor regulates the quantity of the charge passing through it to the cylinder, and hence the degree of compression. As pressures up to 160 and 180 lbs. per square inch are attained during compression, much care is necessary in cooling the cylinder and combustion chamber. Ignition is by electricity, except in engines below 10 H.P. Smaller engines are started by hand, by shifting the exhaust cam on the valve shaft, and holding the exhaust open during the compression stroke; for engines above 12 H.P. compressed air is used, to supply which, either from the engine itself or from an auxiliary motor, about 2 H.P. are required. Single-acting Koerting engines are made with one cylinder from 2 to 165 H.P., above this size up to 350 H.P. with two cylinders side by side, and run at 260 to 135 revolutions per minute. The pistons of engines above 100 H.P. are cooled with water.

An important novelty in gas engines has been the introduction of the Koerting two-cycle double-acting type, which in its construction somewhat resembles a steam engine. This interesting and well-designed motor

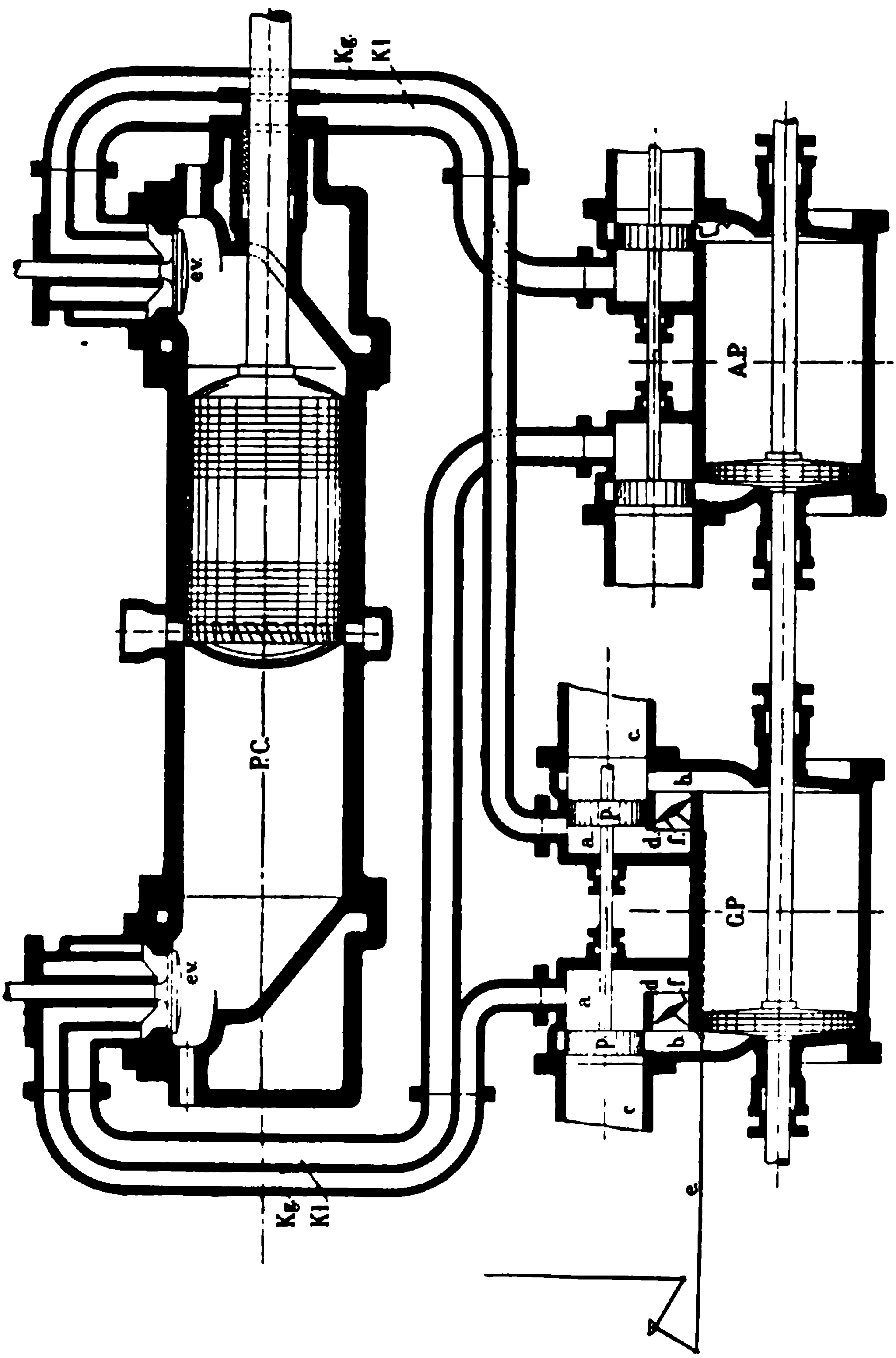


Fig. 83.—Koerting Two-cycle Engine—Sectional Plan.

has, like the Clerk, one working cylinder and two pumps for gas and air. There is one crank, and one admission valve at either end of the cylinder, driven by cams from a small shaft worked by the main shaft; the same

shaft serves the two electric igniters at either end. There is no exhaust valve, and its absence is an advantage in large engines, in which the exhaust valve is a source of difficulty, because of the power required to lift it, and the high temperature of the burnt gases. These are discharged through a ring of slots round the centre of the cylinder, uncovered by the piston at each stroke. The double-acting gas and air pumps, which deliver to each end of the motor cylinder, are worked by a common rod, driven from a crank disc at the end of the motor shaft; and two piston valves worked by an eccentric uncover and close the suction and delivery passages. The pumps are set 110° in advance of the motor piston, and the slight pressure in the delivery passages is utilised to procure a scavenger blast of air, and a stratification of the incoming charge. The length of the motor piston is equal to that of the stroke, less the exhaust ports, which occupy about one-tenth of the cylinder.

Fig. 83 shows the working method and Fig. 84 the action in the motor cylinder, which is as follows:—Beginning with ignition of the charge on one face of the piston at the dead point, the expansion of

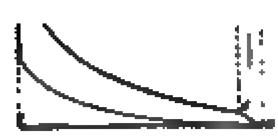


Fig. 84.—Koerting Engine—Section of Cylinder with Diagram.

the gases drives out the piston. At nine-tenths of the stroke the exhaust ports are uncovered, and the pressure falls to atmosphere. Immediately after, and before the dead point is reached, the admission valve opens; a charge of air enters, drives out the products of combustion, and is said to form a neutral cushion between them and the incoming charge. Gas and air in suitable proportions are next admitted, the piston begins to return, covers the exhaust ports, the charge is compressed during the remainder of the stroke to about 150 lbs. per square inch, and the cycle

recommences. The same operations are repeated on the other face of the piston. Thus expansion and compression occupy nine-tenths of each stroke, and admission and exhaust only one-tenth.

The method of obtaining the scavenger charge of air is shown at Fig. 83. The gas and air pumps have the same stroke, but the diameter of the air pump is about one-fifth larger. Gas and air are drawn in through piston valves *p p*, which uncover first the suction and next the delivery passages to the cylinder, through *c*, *b*, and *d*. When the charging stroke of the air pump is ended, the suction passage is shut off by the piston valve, the delivery passage is uncovered and air, at a pressure of about 7 lbs. per square inch, is forced into the passages leading to one or other end of the motor cylinder. In the gas pump the piston valve keeps the connection between *c* and *b* open, not only during the suction, but also during part of the return stroke. As the pumps are in advance of the motor piston, the opening of the gas delivery passages coincides with that of the admission valve. Air has already filled the air passage and the end of the gas passage, and when the admission valve opens it rushes into the cylinder, and displaces the burnt products, before the charge of gas and air, in regulated proportions, enters. As shown in Fig. 83, the two do not mix till they reach the admission valve, striking as they enter the cylinder against a projection below the valve (Fig. 84) to ensure their thorough mixing. The scavenger charge of air is said to prevent the escape of any fresh gas, it cleanses and cools the cylinder, and premature ignition cannot take place.

The governor acts upon the throttle valve *f* (Fig. 83). The gas pump being so arranged that during the first half of its delivery stroke part of the gas drawn in is returned to the suction passage, the governor, working through a series of levers and a slot link, regulates the opening of the throttle valve, and sends on more or less gas to the cylinder, according to the load. As the quantity of air is always the same, the compression of the charge is only slightly reduced, and ignition is always assured, because the richest mixture is forced by the projecting spur to pass near the igniter. This method of governing is especially suited to blast-furnace gases, which being weak are diluted with a relatively small quantity of air. The cylinder and working parts are carefully cooled, and the combustion chamber is ribbed externally, to afford a large cooling surface to the water in contact with it. The hollow piston-rod carries an inner concentric tube, through which water passes to the piston, and returns through an outer tube. The water is supplied under pressure from a small pump, and passes to and from the piston-rod through telescoping tubes; jointed rods are also sometimes used. The exhaust ports are covered at each stroke by the cooled piston. The engine is started by compressed air admitted through a slide valve, at a pressure of 90 to

150 lbs. per square inch, according to the size of the engine, and sent to the cylinder from a small compressor, usually driven by an electric motor.

The two-cycle Koerting engine has been extensively adopted for large powers, especially abroad, where many important installations, chiefly driven with blast-furnace gases, are at work. It is made with one cylinder from 400 to 1,500 H.P., with two cylinders side by side up to 3,000 H.P.; piston speed 700 to 800 feet per minute. Including the engines supplied by their licencees, MM. Koerting have up to now built over a hundred two-cycle engines, of powers varying from 150 to 2,000 H.P., and developing a total of about 100,000 H.P. Of these, 4,300 H.P. are supplied by Mond gas, 76,500 H.P. by blast-furnace gases, 7,200 H.P. by producer gas, and 600 H.P. by coke-oven gases. The engines are made in England by Messrs. Fraser & Chalmers for blowing engines, compressors, and roller mills, and by Messrs. Mather & Platt, of Manchester, for driving dynamos and other purposes. The De La Vergne Machine Company, New York, are the American patentees, and have built the largest plant yet at work, comprising 16 two-cylinder engines driven with blast-furnace gases, each developing 2,000 H.P., thus giving a total of 32,000 H.P., which is shortly to be increased to 42,000 H.P.

Messrs. Mather & Platt construct the Koerting engine, single cylinder, double-acting, in sizes from 500 to 1,000 B.H.P., and twin cylinder from 1,000 to 2,000 B.H.P., with a speed of 125 to 83 revolutions per minute. They have built a 700 H.P. single cylinder engine worked with producer gas for the Castner-Kellner Alkali Company, the largest of its kind in England, and have two others in hand, each developing 1,000 H.P., to work with blast-furnace gases, and two of 700 H.P. and 500 H.P. respectively, to be driven with producer gas. Fig. 85 shows the 700 H.P. single-cylinder engine mentioned above. The largest Koerting installation in Germany is at the Gutehoffnungs Hütte, where there are five engines worked with blast-furnace gases, and developing a total of 4,000 H.P.

A large number of tests have been made on Koerting engines, including several on the earlier types. Trials were carried out at Hanover in 1890 by Prof. Fischer on a 20 B.H.P. engine, giving a consumption of 25 cubic feet of German gas per B.H.P. hour. A later trial by Dr. Epstein in Frankfort in 1893 on a 35 B.H.P. engine showed a consumption of 19 cubic feet of gas per B.H.P. hour. An important test was made in 1900 by Prof. Meyer on a 350 H.P. two-cycle engine, worked with producer gas from a Koerting generator. The engine gave at full load 480 B.H.P. Particulars of the trial will be found in the tables. The consumption of gas was 81·5 cubic feet per B.H.P. hour, and the heat efficiency per B.H.P. 24·1 per cent.

Fig. 85.—700 H.P. Koerting Two-cycle Gas Engine at the Castner-Kellner Alkali Works. Made by Messrs. Mather & Platt.

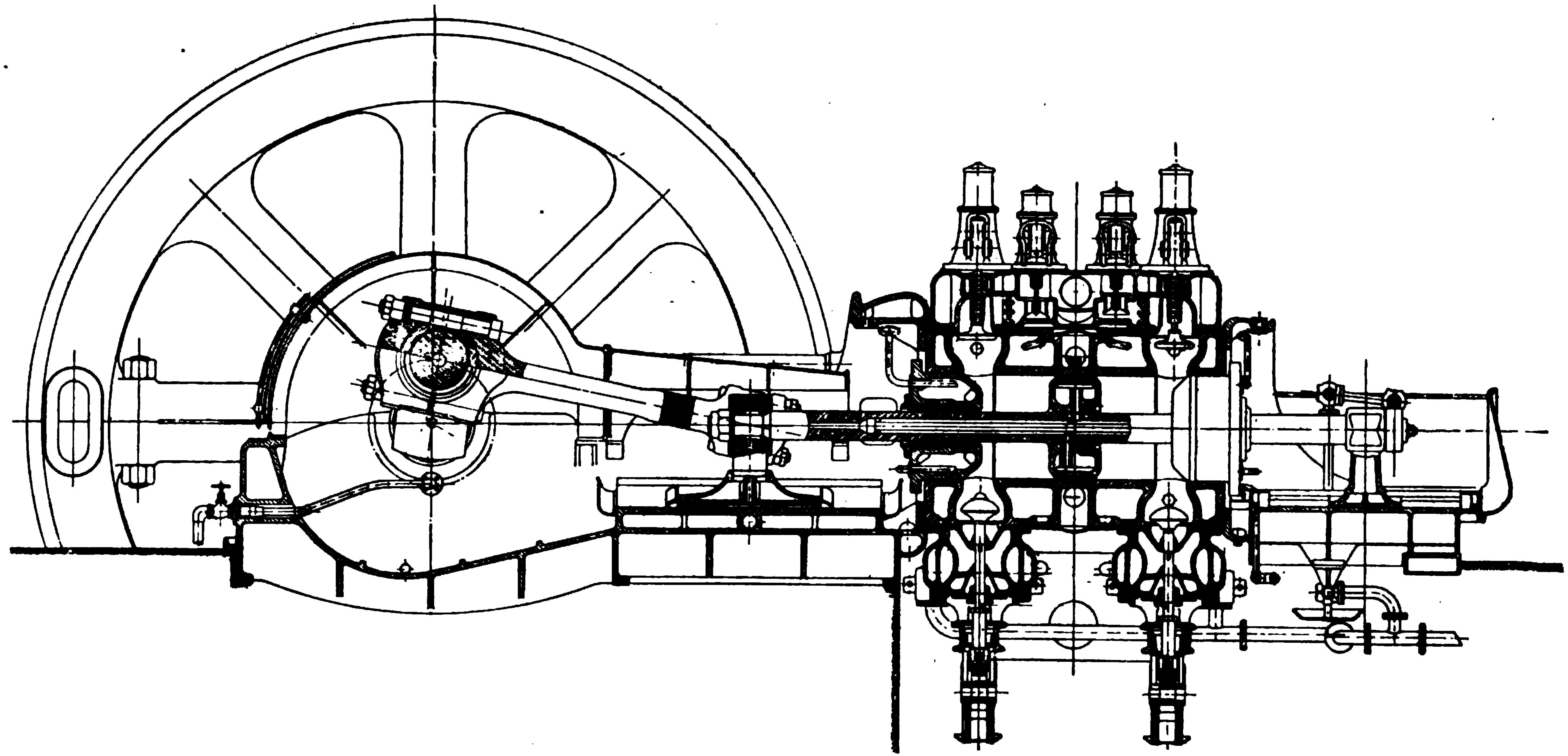


Fig. 86.—Nuremberg Double-acting Engine—Longitudinal Section.

The Koerting two-cycle engine is also made to work with blast-furnace gases by the **Siegener-Maschinen-Bau Gesellschaft,** who exhibited a 700 H.P. engine at the Düsseldorff Exhibition of 1902, where the new type was first brought to public notice. This firm build these double-acting motors in sizes from 200 to 1,600 H.P., and have already constructed eight single-cylinder engines from 200 to 800 H.P., and two twin-cylinder engines, one of 1,000 H.P., and the other of 1,600 H.P. These have been supplied to various iron works in Germany and Luxemburg; two are at the Hörde Works, the first in Germany to utilise blast-furnace gases to drive engines. The blowing engines make from 80 to 100 revolutions, with a piston speed of about 600 to 700 feet per minute. A Koerting two-cycle engine was also shown at Düsseldorff by Geb. Klein, of Dahlbruch.

The **Vereinigte Maschinen-Fabrik Augsburg** and **Maschinen-Bau Gesellschaft Nuremberg** hold a front rank among German firms who have of late years especially devoted themselves to the production of large power gas motors, built on steam engine lines, and worked with producer or blast-furnace gases. Like other first-class houses abroad, they seldom make the smaller sizes, but build large engines of two types, the Diesel (see Part II.), and engines of the usual four-cycle kind. For the latter they have adopted the double-acting system, as seen at Fig. 86. There is one cylinder closed at both ends, with two exhaust valves opening one before the other, two admission valves above them, and a mixing valve, through which the gas and air pass alternately to either end of the cylinder. The piston works on to the crank through a connecting-rod and crosshead. In a 750 H.P. single-cylinder engine put down in 1902 at the Rhenish Steel Works, Meiderich, the valves were worked by cams from the valve shaft, and remained open throughout the admission stroke. The governor acted on the automatic mixing valve, and regulated the quantities of gas and air passing through it to the admission valve, according to the load. The latest arrangement, shown at Fig. 87, resembles the Deutz and Crossley governing gear. The admission valve is held open by the rod $d\,e$ and lever $e\,f\,g$ throughout the admission stroke, and closed by the spring F. The double-seated mixing valve in the same valve chest, worked by levers $m\,f\,l$, and the rod $l\,i$, is closed by a weaker spring F_2, admits gas and air in constant proportions, and under normal conditions is also opened throughout the admission stroke. If the load increases, the governor shortens the time of contact of the rod i with e and b, and the mixing valve is opened for a shorter period, and closed by the spring F_2, when roller b slips off the cam a. As the movement of the admission valve is always the same, the quantity, but not the quality, of the charge is varied.

The type adopted by the Nuremberg firm for two-cylinder motors is the tandem, and for large powers two tandem engines side-by-side, with four cylinders, all double-acting. This method of construction gives very large powers, with relatively small cylinder dimensions. The weight of the piston and rod is taken by slides; the frame carries the front slide, forming the crosshead, the bearings for the crank shaft, and the oil tank. In the latest type the valves are worked by eccentrics from the auxiliary shaft, which, as the engine is double-acting, makes the same number of

Fig. 87.—Nuremberg Engine—Valve Gear and Governor.

revolutions as the main shaft. The time of electric ignition can be varied while the engine is running. All the internal parts are separately lubricated by oil under pressure, which can thus be supplied to any particular part, if necessary. The external parts are lubricated from the oil tank in the base of the engine. Special care is bestowed on cooling the working parts, the supply of water is carefully regulated, and its temperature taken by thermometers at the various outlets. About $6\frac{1}{2}$ gallons are required per B.H.P. hour. The piston and piston-rod

are cooled by water from a special pump, worked direct from the crank shaft. The engine is started by compressed air.

The Nuremberg gas engines are made in sizes from 150 to 1850 H.P., with one, two, or more cylinders, and run at 90 to 150 revolutions per minute. During the last two years (1904) the firm have made, or have in hand, sixty-six engines worked with blast-furnace, producer, Mond, and coke-oven gases for driving dynamos, mills, and blowing engines. Of the latter they make a speciality. Their largest plant is at Madrid, where there are six engines, each developing from 1,800 to 2,000 H.P., directly coupled to dynamos, and worked by Mond gas made from Spanish lignite. The gas has a heating value of 123 B.T.U. per cubic foot, and the exhaust gases are used to generate steam in the producer.

Soest.—The firm of Louis Soest, of Reisholz, are also makers of gas engines, chiefly for large powers, of the ordinary horizontal four-cycle type. In their motors the front part of the long piston serves as the crosshead. The engine and valve chest are cooled with water, and in the larger engines the exhaust valve also. The admission and exhaust valves are placed one above the other, and are worked by levers and cams from the valve shaft, geared 2 to 1 to the main shaft. The valve seats are so placed that the inner cylinder wall is cooled both inside and out, an arrangement also found in the Nuremberg engine. The admission, first of air, then of gas, is through a piston valve, the movement of which can be adjusted by a screw, and the proportions thus varied. The governor acts through rods on throttle valves in the gas and air passages; the quality of the charge is always the same, the quantity alone being regulated according to the load. As the charge is fired by an electro-magnetic apparatus driven from the crank shaft, ignition is always assured. The cylinder and bearings are lubricated by sight feeders, the crank by centrifugal lubrication. Engines above 30 H.P. are started by air from a compressor, at a pressure of 200 to 280 lbs. per square inch, the exhaust valve being meanwhile kept open during the compression stroke. The engine is made in sizes from 10 H.P. upwards, and runs at 220 to 170 revolutions per minute. Up to 150 H.P. it is built with one cylinder, double-acting, or two cylinders side-by-side, single-acting; above that size, tandem, double- or single-acting. MM. Soest have supplied a large plant with two cylinders, each developing 700 H.P., at Aix La Chapelle, to work with blast-furnace gases. A 300 H.P. two-cylinder engine was shown at Düsseldorff.

The **Dingler Maschinen-Fabrik**, Zweibrücken, are another important German firm, who confine themselves wholly to the construction of gas engines above 150 H.P. These they build of the four-cycle type,

double-acting, single cylinder, or, if more power is required, with two cylinders, tandem. The water-cooled exhaust valve is in the lower part of the cylinder, thus any dust or dirt is blown out with the gases. All the valves are driven from the auxiliary shaft, which rotates at the same speed as the crank shaft, to which it is geared by helical wheels. The opening of the admission valve is constant, and air and gas pass to it through a piston valve, the stroke of which is also constant, hence the proportions of the two do not vary. The centrifugal governor on the valve shaft acts on the closing of the admission valve, and thus regulates the quantity of the charge entering the cylinder, and hence the compression. By a special patented arrangement, it also determines the exact moment of ignition, in accordance with the load, and the amount of the charge admitted. When the governor rises it shifts a small shaft through a series of levers, and causes the admission valve to close, and the charge to ignite sooner. If the engine is made tandem, it carries a carefully packed piston-rod, on which the two plunger pistons run. There are no stuffing-boxes, but the two cylinders are joined by a connecting piece, cooled, like the piston and rod, with water, through which the latter works. For double-tandem engines two pairs of cylinders are coupled. The engine is started by compressed air. The piston and piston-rod are lubricated by oil under pressure, the other parts by centrifugal lubrication. The Dingler engines are made double-acting, single cylinder, from 150 to 600 H.P., and run at 145 to 100 revolutions per minute, and tandem from 500 to 1,400 H.P. for blast-furnace gases. The consumption is given at about 250 to 280 B.T.U. per cubic foot per B.H.P. hour. An experiment was made in 1904 by Prof. Meyer on a 150 H.P. engine, driven with producer gas, in which the consumption of coke was about 1·2 lbs. per B.H.P. hour.

Oechelhaueser.—The demand for large power engines, and the application of blast-furnace and coke-oven gases to drive them, have brought this striking motor to the front. In some respects it resembles the first Atkinson engine, known as the Differential. The latter had not an air pump, like the Oechelhaueser, but in both motors valve gear is practically dispensed with. As hitherto made, the Oechelhaueser has one long cylinder open at both ends, with two pistons, performing between them the functions of admission and compression of the charge, and discharge of the exhaust gases. There is no cam shaft, and the valves usually driven by it are replaced by ports uncovered and shut off by the motor pistons during their stroke. These pistons work in the horizontal cylinder in opposite directions on to the same crank shaft, through three cranks 180° apart. The two outer cranks are connected by rods and crossheads with a cross piece at the back of the cylinder, through which the piston of the back cylinder works. The double-acting pump on the

same axis as the motor cylinder is at the back of the cross piece, and its piston is driven from it.

Fig. 88.—600 Horse-power Oechelhaeuser Two-cycle Engine.

Fig. 88 gives a plan of the engine, and illustrates the action. G is the air pump, K_1 and K_2 the two motor pistons. Beginning with the point in the stroke, where the two pistons are almost close together, the charge of gas and air between them is compressed within very small limits to a pressure of 8 or 10 atmospheres above atmospheric pressure. Electric ignition follows, and the two pistons are driven apart by the pressure of explosion, which is in proportion to the heating value of the gas used, and sometimes reaches 355 lbs. per square inch (25 atmospheres). Work is thus done by both pistons on the crank (double motor stroke). Meanwhile the piston of the air pump G has drawn in fresh air through the automatic valve S, and the return stroke of this piston compresses it on its front face, and passes it at a slight pressure through D and the air chamber R into the compression space. On the back face of this piston another series of operations are simultaneously carried out. Here a mixture of gas and air is drawn in through another automatic valve N, and compressed by the pump piston through O into the mixing chamber P, which it enters at the same pressure as the air in R. Piston K_1 having passed the outer dead point of the centre crank, now begins to uncover the exhaust ports C_1, and the products of combustion are driven out. Piston K_2 next uncovers the air port A, and the air under pressure rushes from R into the motor cylinder, sweeping out the burnt products before it, and forming an effective scavenger charge. The admission port Q is then uncovered by piston K_2, and the charge of gas and air, compressed to about 7 lbs. per square inch, enter the motor cylinder. The makers of the engine assert that none of this fresh charge escapes through the exhaust with the scavenger blast of air, because the volume of the cylinder is so proportioned that, even when running at maximum load and power, the charge only occupies about 70 per cent. of it. Both motor pistons now begin the return stroke, the mixture is compressed between them, and the cycle recommences.

If there are only slight variations in the speed, the governor acts upon the relative proportions of gas and air, and alters the composition of the charge; if the speed is varied within wider limits, it regulates the quantity of the charge through the mixing valve cock H and the return slide valve V in the passage D. Part of the compressed charge passes from O into the suction pipe N, and is thence transferred to the other side of the pump, instead of passing, as usual, to the motor cylinder. In the latest system, the governor acts separately upon the admission of gas and of air.

In this interesting engine compression, ignition, and expansion of the charge occupy respectively seven-eighths of the stroke, while admission and exhaust are effected during the remaining one-eighth of each stroke. Fig. 89 shows an indicator diagram; the exhaust opens at *a*, and at *c*

compression of the gases up to 140 lbs. per square inch begins. An unusual feature is that water is sprayed on to the exhaust gases to cool them. The latest engines are fitted with two electric igniters. In some motors, gas alone enters through the admission ports, and the charge is formed in the motor cylinder itself; this arrangement depends upon the kind of gas used.

The advantages of the Oechelhaueser cycle are that a motor stroke is obtained at each revolution instead of at every other revolution, and as this is effected by two working pistons, the power is said to be increased four-fold. The necessity for two cylinders, motor and pump, does not cause difficulty, because for large powers two cylinders are practically indispensable. Admission and exhaust are effected in one stroke instead

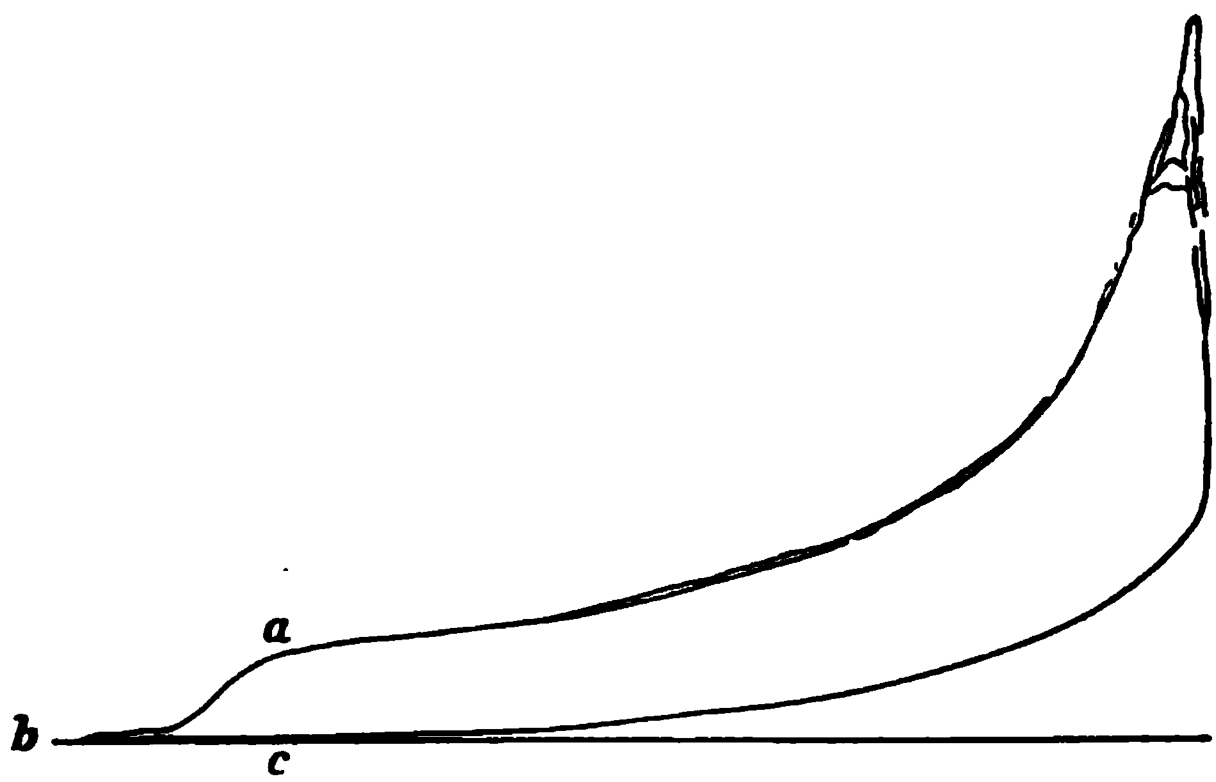


Fig. 89.—Oechelhaueser Engine—Indicator Diagram.

of in two, and the cylinder dimensions are smaller for the same power than in the four-cycle type. Thus a 1,000 H.P. single-cylinder Oechelhaueser engine has a cylinder diameter of only 36·8 inches = 935 mm. For work with poor gases, the simplicity of the long smooth cylinder, without the complication of a cylinder head and valve chest, and the absence of valves are also advantages, because dust cannot settle in the working parts. The only external gear required is a small auxiliary shaft to drive the governor, igniters, and the starting valve. When used for blast-furnace work, the blowing engines can, it is said, be driven direct from the motor piston without a stuffing-box, and can themselves be utilised, as at Hörde, to supply the scavenging charge of air. On the other hand, the engine has three cranks and three pistons, and the connections are somewhat complicated. The governing at first was said not to act efficiently, but this has now been remedied.

The Oechelhaueser engine (Fig. 90) is made for large powers by several important German firms. The **Deutsche-Kraft Gesellschaft** are the

Fig. 90.—Borsig-Oechelhaeuser Two-cycle Single Cylinder 1,800 H.P. Gas Engine.

chief makers, and hold the patents; they build engines from 250 to 3,000 H.P., with a speed of 150 to 90 revolutions per minute, to work with blast-furnace, producer, and coke-oven gas. Affiliated firms in Germany are MM. **Borsig**, of Berlin-Tegel; the **Berlin-Anhaltische**, Kölnische, and **Ascherslebon Maschinen-Bau Gesellschaft, Lang,** in Hungary; and **Messrs. Beardmore**, of Glasgow. MM. **Borsig** have adapted the engine to work with lighting gas, and build it single cylinder from 250 to 1,500 H.P., and with two cylinders from 500 to 3,000 H.P., with a speed of 150 to 94 revolutions per minute.

An excellent trial was made in October, 1903, by Professor Meyer on a 500 H.P. Borsig-Oechelhaueser engine, driven with coke-oven gas, and directly coupled to a blowing engine. Full details will be found in the Tables. The mechanical efficiency of the engine was about 80 per cent., mean heating value of the gas 363 B.T.U. per cubic foot, heat efficiency per B.H.P. 27·6 per cent. As the engine was originally constructed to work with blast-furnace gases of little more than one quarter the heating value of coke-oven gas, it was found necessary to utilise the pump to deliver air only, and to admit the gas to the cylinder through a small separate pump. Doubts had been raised whether the three cranks might not prove a source of weakness. Professor Meyer determined this question by calculating the stresses on the crank shaft, and found that it might be rotated at a much higher speed than the normal without danger. About 45 Oechelhaueser engines, of powers varying from 250 to 3,200 H.P., have been made by the various firms. Of these the Borsig firm have supplied twenty, with an aggregate of about 12,000 H.P., driven by coke-oven, blast-furnace, and producer gases. The most important plants are at Gijon, in Spain, where there are nine single cylinder engines worked with Mond gas, developing 3,400 H.P., and used to drive dynamos, and at the Ilsede Iron Works, where six engines are worked with blast-furnace gases, two of 1,000 H.P., two of 1,600 H.P., and two of 500 H.P. These powerful motors drive dynamos and blowing engines, and supply power to the rolling mills at Peine, five miles distant. Fig. 90 gives a view of the latest Borsig-Oechelhaueser engine, shown at the St. Louis Exhibition.

Adam.—The Adam vertical gas engine, formerly constructed by the Maschinen-Bau Gesellschaft at Munich, resembled the earlier Koerting in some respects. Ignition was effected by propagation of flame; the governor acted on the exhaust valve, and the products of combustion were re-introduced into the cylinder, instead of a fresh charge, if the speed was too great. The engine was of the usual four-cycle, single-acting type, of which Fig. 91 gives a sectional elevation. The organs of admission, distribution, ignition, and exhaust were worked by a small auxiliary shaft K_1, driven from the crank shaft K. Gas and air were

admitted into the mixing chamber, and passed through an automatic valve and the wide passage *b* into the cylinder A with piston P. The ignition chamber V was enclosed within another, in which a small vertical piston *p* worked. At the moment of ignition the compressed gases from the motor cylinder entered the tube from below, and ignited at the opening *d*. The valve piston then descended, shutting off communication from above, and the flame shooting back into the cylinder ignited the rest

Fig. 91.—Adam Gas Engine—Sectional Elevation. 1888-1899.

of the charge. The speed was regulated by the ball governor G, which kept the exhaust valve open a longer or shorter time, by shifting the roller *e* from a smaller to a larger cam.

A 25 H.P. twin-cylinder vertical engine was shown at the Munich Exhibition in 1888; and another of 30 H.P., with four cylinders, at the Frankfort Electrical Exhibition in 1891. In these engines the cylinders were placed diagonally to each other, the centre of the axis of each being

in line with the centre of the crank axis. The four pistons worked opposite each other in pairs on to two cranks 180° apart, and one crank shaft; the up stroke of one of the pair of pistons was always more rapid than the corresponding down stroke of the other. A trial upon a two-cylinder 11 B.H.P. engine was carried out by Professor Schröter at Munich in 1889. At Nuremberg in 1888, in an 11·7 B.H.P. engine, the consumption was 27 cubic feet of town gas per B.H.P. hour, including the external flame. Later experiments on a 6 B.H.P. engine showed a consumption of 23 cubic feet of German lighting gas per B.H.P. hour.

The construction of this engine has now been given up, and the Maschinen-Bau Gesellschaft München make the **Güldner** engine, more especially for work with suction gas producers. A small two-cycle type was brought out in 1893, of which the present engine appears to be a development. The motor is vertical, with the crank shaft below, surrounded by a reservoir of air. In the down stroke of the piston, the exhaust gases are first discharged; compressed air is then forced from the crank chamber, through a vertical passage into the upper part of the cylinder, where it acts as a scavenger charge, and effectually clears out the burnt products before the admission valve opens to admit gas and air. The return stroke compresses the charge, the gases are fired electrically, and are expanded in the next down stroke. A description of several engines more or less on the same lines, notably the Day, will be found in the earlier editions of this book. In a test made in September, 1903, by Professor Schröter on a 30 H.P. engine driven with lighting gas, the high heat efficiency of 42·7 per cent. per indicated H.P. was attained at maximum load, and a mean heat efficiency of 28·5 per cent. per I.H.P. hour, when worked with a suction gas producer fired with anthracite. The Güldner engine is made vertical only, single cylinder, in sizes from 10 to 100 B.H.P., two cylinder from 75 to 200 H.P., and runs at 260 to 150 revolutions per minute.

Benz.—One of the best designed of German engines was the Benz, patented in 1884, and constructed by the Rheinische Gas-Motoren Fabrik at Mannheim. In it the problem was again treated, how to obtain a motor impulse per revolution, without the additional complication of a second pump cylinder. The loss of power and want of regularity in four-cycle engines, giving an explosion only every two revolutions, were thus avoided. In the opinion of Professor Witz, the difficulty was more completely and satisfactorily solved in this than in any other engine.

Fig. 92 gives an elevation, and Fig. 93 a plan of the Benz engine. A is the horizontal motor cylinder closed at both ends, in which the piston P works, A^1 the small gas pump with plunger piston P^1. The air receiver in the base of the engine B is shown at Fig. 92, and the compressed air passes through D to the cylinder. S is the slide valve, worked by eccentric

g on the crank shaft, through which and the port *m* air is drawn into the front part of the cylinder. During the next forward stroke, the side of the piston next the crank compresses it into the receiver below, from whence a charge of compressed air enters the back of the cylinder. The lift valve *a* and the exhaust E are worked from the crank shaft by an oblique rod indicated by dotted lines in Fig. 92, the lever C and cam *d*. The piston P^1 of the gas pump is fixed to the crosshead, and moves with it. The gas is admitted into the pump A^1 through a valve connected to the governor,

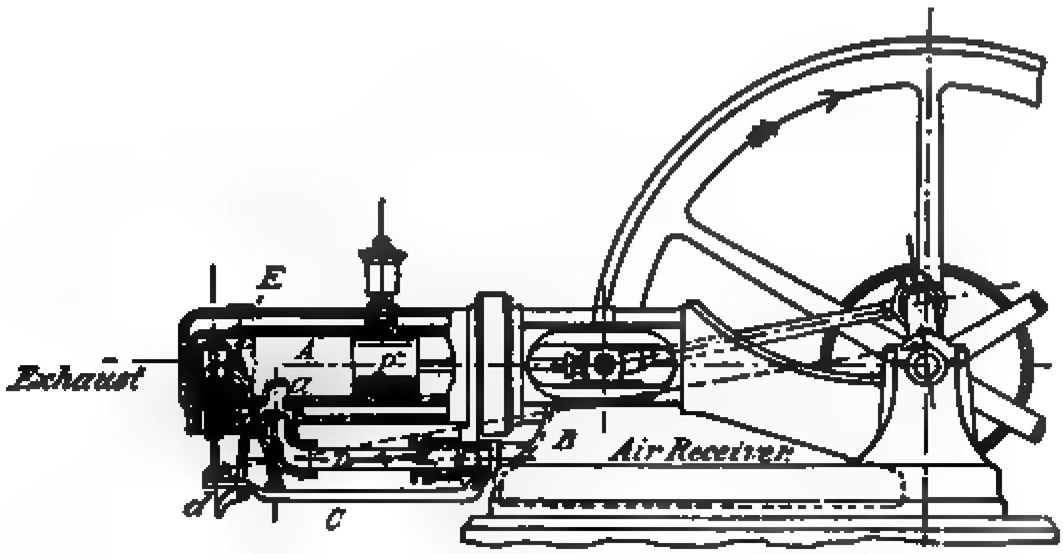


Fig. 92.—Benz Gas Engine—Elevation.

Fig. 93.—Benz Gas Engine—Plan.

which lifts it for a longer or shorter time, according to the speed. The return stroke of the pump compresses the gas into the motor cylinder, through the lift valve *f*, which at the end of the pump stroke is pushed up from the lever *n* and eccentric *h* on the main shaft. Electric ignition was employed from the first. The manufacture of the Benz engine has now practically been given up, except for motor cars.

Daimler.—This engine was constructed by the Daimler Motoren Gesellschaft at Cannstadt, near Stuttgardt; the French makers are

MM. Panhard and Levasseur at Paris. A Daimler motor was shown at the Paris Exhibition of 1889. It had several novel and interesting features, the chief of which were its great speed and the purity of the charge, due to the complete expulsion of the products of combustion. The original motor had one cylinder; the later type is vertical with two cylinders. It is now chiefly driven with oil, and as a petroleum motor for small powers has had much success.

In the modern engine the parts are enclosed, to protect them from dust, and a reservoir is thus formed, into which air is introduced, and compressed by the action of the piston. There are two cylinders and two pistons, placed diagonally at a slight angle above the horizontal motor shaft, and working down through two connecting-rods upon two cranks. The explosion in one cylinder is sufficient to drive both cranks through one revolution. The engine is of the four-cycle type, the usual operations being performed alternately in each cylinder. The gases are admitted through an automatic valve during the down stroke of the one piston, and simultaneously expanded by the down stroke of the other, which is the working stroke. The next up stroke compresses the charge in one cylinder into the hot ignition tube, where it is fired without a timing valve, and expels the burnt products in the other. There are two air admission valves to each cylinder. One in the centre of the piston is lifted by forks during the up stroke, and closed by the pressure above it. The other air valve at the side opens automatically to admit air from without to supply the reservoir. As the latter fills, the pistons descend, compressing the air below them. Having reached the lower dead point, they begin to return, the products of combustion being behind the one, and the fresh charge behind the other. The piston valves are then lifted, the air from below mingles with the fresh charge in one cylinder, and is further compressed; in the other it drives out the products before it. The speed is regulated by the governor acting on the exhaust valve by means of a lever, and keeping it closed a longer or a shorter time, according to the load.

Dürkopp.—The Dürkopp gas engine, made by the Bielefelder Nähmaschinen-Fabrik, is another four-cycle motor, now little made. In the vertical type the cylinder, and the admission, ignition, and exhaust valves are below, and the connecting-rod works upward on to the crank. The motor shaft is above, and carries on one side the flywheel and driving pulley, on the other a vertical side shaft worked by wheels 2 to 1. In both the horizontal and vertical engines all the valves are driven by cams. Air and gas are admitted at the side, and pass into the mixing chamber through a valve lifted by a cam, which also opens the exhaust. To obtain a quiet discharge, part of the gases are allowed to escape through a smaller valve, before the main exhaust valve opens.

Ignition is by hot tube. The rotary ball governor acts on the "hit-and-miss" principle on the gas admission valve, and closes it if the normal speed is exceeded.

Dresdener Gas-Motor.—The gas engine brought out by the Dresdener Gas-Motoren Fabrik (Hille's patent) is a compact and well-made engine, single-acting, both vertical and horizontal. About 600 engines are sold annually, and the makers claim to have supplied a total of 5,500, developing 35,000 H.P. Like many engines which have appeared since the expiration of the Otto patent, it adheres very closely in working details to that type. It has the usual sequence of operations, admission, compression, explosion plus expansion, and exhaust, and there is one explosion for every two revolutions. The admission and exhaust valves are worked by cams from a valve shaft driven from the crank shaft in the usual way. A slide valve at the side of the cylinder, acted on by a valve-rod from the same shaft, governs the hot-tube ignition in some of the smaller sizes, in others there is no timing valve. Engines above 12 H.P. are fitted with electric ignition. For small powers, from ½ to 6 H.P., these engines are made vertical, with a pendulum governor, and run at 180 to 230 revolutions per minute. For powers from ½ to 100 H.P., a horizontal single-cylinder type, making 250 to 150 revolutions per minute, is used, with a centrifugal governor. Where great regularity is required, as for electric lighting, the engines have two flywheels, and are made in sizes from 3 to 100 B.H.P. In the latest types the speed is regulated by a pendulum governor, acting on the valve admitting the charge to the cylinder. Under normal working conditions this valve is always held open by a spring, the gas and air valves being driven by gearing. A lever worked by a cam carries a projection, which usually passes another on the lever of the admission valve, and the latter remains open. If the normal speed is exceeded, the pendulum governor causes the two projections to strike against each other, the admission valve is closed, and no charge reaches the cylinder. In other engines the governor acts in the same way on the gas valve. Trials on the Dresdener engine have been made by Professors Schöttler and Levicki. The former tested a 16½ B.H.P. engine at Dresden, and found the consumption to be 24 cubic feet of town gas per B.H.P. hour. Professor Levicki experimented on a 6·8 B.H.P. engine, the consumption in which was nearly 26 cubic feet of town gas per B.H.P. hour, and the mechanical efficiency 90 per cent. These engines are also made to work with power gas from generators on the Dowson system, supplied by the makers, and with suction gas producers, more than fifty of which are at work.

Kappel.—The Maschinen-Fabrik Kappel, at Chemnitz, Saxony, have introduced a gas engine, similar in many respects to the Otto. In the

earlier type the exhaust was opened by two projections and a roller worked from an eccentric on the valve shaft; the second projection opened the exhaust at starting, during the compression stroke. Air and gas were admitted through lift valves, and ignition was through a small slide valve at the side of the cylinder. As now made, the exhaust, gas, and air admission valves are worked by cams from a side shaft. Hot-tube ignition is only used for the small sizes, above 10 H.P. ignition is by electricity. The engine is governed by a pendulum or rotary ball governor, which shifts the stepped cam opening the gas valve according to the load. In engines worked with producer gas the governor acts on both the gas and the air passages. The engine is started in various ways. If a steam engine is available, it can be connected by friction coupling. Sometimes compressed air is used; the smaller sizes are set in motion by a handle on the crank shaft with a patent safety arrangement, to prevent the engine starting backwards. The method most recommended is a small auxiliary motor which, if the engine is driven by gas from a suction gas producer, can also be used for the air blast to start combustion. The piston is lubricated by oil under pressure, the bearings and driving gear by oil from a tank below the crank shaft. The engine is made horizontal from 1 to 120 H.P., and runs at 240 to 160 revolutions per minute. A small vertical type for domestic use is also made, to work with either gas or oil, from 1 to 3 H.P., with a speed of 350 revolutions per minute.

Lützky.—The construction of this interesting little engine by the Nuremberg Maschinen-Bau Gesellschaft has now been relinquished in favour of the larger and more important engines they make in conjunction with the Augsburg Maschinen-Fabrik (see p. 165), but it had several ingenious features, which should not be passed over. As made a few years ago, the engine was vertical, with the cylinder at the top, the piston working down through a connecting-rod upon the crank shaft, placed in a hollow conical base plate below. Admission was by two automatic lift valves at the top of the cylinder. Through the first the gas passed into the mixing chamber, the second rose to admit the charge of gas and air into the cylinder, the two being so connected by levers that the lift of the admission valve also raised the gas valve. Neither valve could act while the exhaust was open. The governor regulated the speed by holding the exhaust closed, on the "hit-and-miss" principle. In a type described by Schöttler, the admission valve was opened by rods acted on by a tappet on a disc, rotated by a lever from the crank shaft. The governor operated on the disc in the same way as already described. A 6 H.P. Lützky engine was tested by Professor Schöttler in Germany. At a mean speed of 200 revolutions per minute, the consumption of town gas was 24 cubic feet per I.H.P. hour. Good drawings of this engine

will be found in the *Zeitschrift des Vereines deutscher Ingénieure*, August 22, 1891.

The construction of gas and oil engines by the Berliner Maschinen-Bau Gesellschaft, formerly Schwartzkopf (Kaselowsky's patent) has now been discontinued.

Sombart.—The Sombart engine, formerly made by the firm of Buss, Sombart & Cie., afterwards by Fried. Krupp, Grusonwerk, Magdeburg, and by the combined firms of the Maschinen-Fabrik Augsburg and Nuremberg, was first exhibited in 1886. It is one of the oldest German engines, and was originally made vertical, the charge being admitted through a slide valve and fired. In some respects it resembled the Adam and Koerting, and the ordinary four-cycle was used. Ignition was obtained by the propagation of an external flame through a passage in the slide valve, an arrangement afterwards superseded by hot-tube ignition. The gas and air were admitted through a slide valve acted on by a rod from an eccentric on the valve shaft, the exhaust was opened from it by means of a roller and levers.

The makers of the engine considered that a high speed was inadvisable, and few of their motors were intended to be driven at more than 150 revolutions per minute. They maintained that it is more advantageous to run a gas engine at a comparatively low speed, and that the gain in power obtained by increasing the number of revolutions is counterbalanced by the wear and tear, and the greater consumption of gas and oil. Two vertical and two horizontal engines were exhibited at Chicago. In the horizontal type all the valves were worked by cams on a valve shaft driven 2 to 1 from the crank shaft. The speed was controlled by an inertia governor, acting by the partial or total suppression of gas, and could be varied while the engine was running. In some types ignition was effected by a lift valve driven by a lever from the rod working the admission valve, and in engines intended for driving dynamos the quantities, both of gas and air, were automatically varied by the governor, in accordance with the load. Drawings of the earlier type of the Sombart engine will be found in Schöttler, and of the later in Witz.

Capitaine—Theory.—Among engines introduced within the last twenty years, an interesting and original motor is the vertical Capitaine. In a paper communicated to the *Verein deutscher Ingénieure* (vol. xxxiv. of the *Zeitschrift*), the inventor, Herr Capitaine, maintains that the greater the number of revolutions, the better results will be obtained. At the same time he advances the somewhat novel point, that the piston speed may be quite different from, and independent of, the speed of expansion of the gases. Though usually classed together, the two are not synonymous, and their effect is by no means the same. If an engine be constructed, running at a certain speed, with a small diameter of cylinder

and a long stroke, the speed of the piston will be considerable, and the speed of expansion relatively small. On the other hand, if another engine, going at the same speed, have a short stroke and a large diameter of cylinder, the piston speed will be relatively small, and the speed of expansion great. Combustion, however, can never be instantaneous, and therefore the speed of the piston should be limited to the rate of com bustion of the charge. In Capitaine's opinion, the Otto engine owes its success partly to the carefully designed ratio between combustion and the speed at which the gases expand. To every speed of revolution in a gas engine, a certain rate of combustion corresponds. Hitherto attempts to increase the efficiency have been made by—1, More or less rapid combustion; 2, Raising the temperature of the cylinder walls; 3, More perfect expansion of the gases; 4, More complete expulsion of the products of combustion; 5, Greater compression. All these improvements, combined with a suitable rate of combustion, have yielded good experimental results. To obtain greater economy in a gas engine, Capitaine considers that expansion ought to be more rapid, and explosion practically instantaneous; the diameter of the cylinder should be increased, and the stroke shortened.

The disadvantages of running at high speed are, the wear and tear of the engine, uncertain ignition, incomplete combustion, and the vibration. Against these drawbacks Herr Capitaine sets the gain of reduction in size and cost. If an engine can be made, without overheating, to run at twice as many revolutions per minute as another, its dimensions may be smaller, it will be lighter, less expensive, and the cost of transport lower. Hitherto, when engines have been tested at high speeds, no great gain in economy has been observed. Being constructed to run at a given number of revolutions per minute, and their ports proportioned to this speed, and to a given rate of combustion, they cannot be expected to work as efficiently, when they are driven at a much higher speed. The whole of the charge cannot reach the igniting chamber of the cylinder at the moment of explosion; part of it is ignited afterwards, and expands too late to act usefully on the piston. Capitaine found, when testing an engine constructed to run at a high speed, that, when making 320 revolutions per minute, an excellent indicator diagram was obtained. When the speed was increased to 800 revolutions, the efficiency was much lower, and diminished in proportion to the increase of speed. The number of revolutions should not be in excess either of the speed of propagation of the flame, or the development of pressure in the gas.*

* See on the subject of speed in gas engines the summary of Dr. Slaby's experiments in Appendix C. The remarks in the text scarcely apply to the latest gas engine practice, in which motors are made for powers so much larger than were usual ten years ago, that the speed of revolution is of necessity kept within moderate limits (1905).

Capitaine Engine.—The piston speed in feet per minute is the same in the Capitaine as in other motors, but the number of revolutions, or speed of expansion of the gases, is said to be doubled. It is also claimed

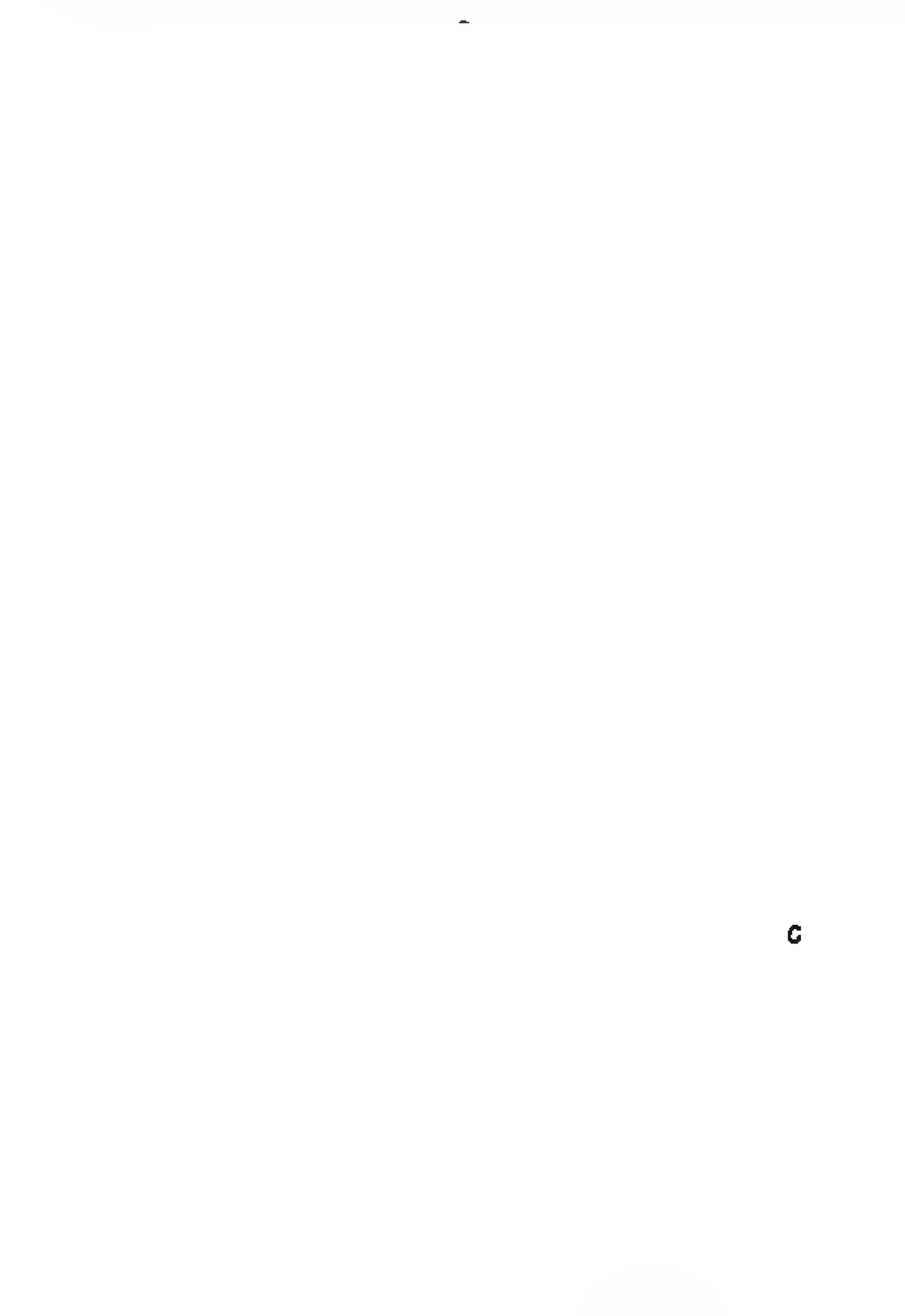


Fig. 94.—Capitaine Gas Engine—Sectional Elevation.

for this engine that the incoming charge is separated from the products of combustion, and not allowed to mingle with them. The engine is of the single-acting vertical four-cycle type, and the disposition of the valves and working parts is similar to that of the Lützky. As originally made the cylinder A (Fig. 94) is at the top, and the piston P works down upon the crank shaft K. Gas and air are admitted from above, through a double-seated automatic lift valve, with spring S. The air enters at D, and passes down into the wide port through the bottom of the valve at *c*, the gas through the upper seat at *f*. Thus they mingle in the annular chamber formed by the valve, which imparts to them a rapid circular motion, and then impinge against a projection *g*, but the wide diameter of the port is said to check their velocity. By this means the fresh charge does not mix with the gases of combustion, which are discharged through the exhaust port E at the side.

The piston having drawn in the charge, the up compression stroke drives it into the hot ignition tube B, into which a portion of the incoming charge has already been directed. As there is no timing valve the gases enter freely, and the mixture is said to ignite more readily, because part of it is already in contact with the hot ignition tube. The exhaust valve E is driven by a rod from an eccentric H on the crank shaft. Above the termination of this rod is a hollow lever, into which the projecting end of the exhaust spindle fits at every revolution. But it is only at every other revolution that a second lever is interposed between them, and the eccentric, pushing up both levers, reaches and opens the exhaust valve. A drawing of the arrangement will be found in Schöttler, third edition.

The centrifugal governor G on the crank shaft acts through a rod *r*, and a catch on the lever opening the exhaust. If the speed be too great the rod is drawn outwards, the knife edge of the lever misses the catch, the exhaust valve remains open, and no fresh charge can enter till the speed is reduced. In a trial on a 3·36 B.H.P. engine, with a cylinder diameter of 6·6 inches and 6·4 inches stroke, and making 300 revolutions per minute, 27 cubic feet of town gas were used per B.H.P. hour. The engine is now made by the Maschinen-Bau Gesellschaft, Leipzig-Plagwitz, and in England by Messrs. Tolch, of Fulham. It has been often exhibited, but is now chiefly worked with petroleum (see Part II.).

The **Berlin-Anhaltische Maschinen-Bau Gesellschaft** were, till lately, makers of engines of the usual four-cycle type. At the Berlin Exhibition of 1896 they showed a 60 H.P. horizontal engine running at 158 revolutions per minute. The gas, admission, and exhaust valves, and a timing valve for the hot tube, were worked by cams from the valve shaft. The engine was started by means of a little vertical ¾ H.P. motor, filled with compressed explosive mixture from the larger engine while

running. This motor carried a second valve in the compression space, through which the compression chambers of the two engines were placed in communication. The ignition tube being shut off, the larger engine was filled with the compressed mixture, the timing valve then released, and the charge fired. As connection with the auxiliary engine was made through an automatic valve, the pressure in the larger cylinder when at work disconnected the two. In an engine giving 14·8 B.H.P. at a speed of 198 revolutions per minute the consumption, in a trial by Professor Meyer, was 17·8 cubic feet per B.H.P. hour of gas of 560 B.T.U. heating value per cubic foot. This firm now devote themselves entirely to the manufacture of the Oechelhaueser two-cycle engine (see p. 173).

The same may be said of the important firm of **Borsig** (Berlin-Tegel) who exhibited a small four-cycle engine at Berlin in 1896, but now build only the Oechelhaueser for large powers, as described at p. 168. In this earlier engine the automatic gas and air admission valves were connected, and both were lifted by the vacuum in the cylinder. The exhaust was driven by an eccentric through vibrating levers working in a slot. A knife-blade connected these levers with the eccentric-rod during the exhaust stroke, but when the admission valve rose it carried with it the vibrating lever and the exhaust valve-rod, and the connection with the knife-blade was missed, till the pressure in the cylinder fell. Through this knife-blade the governor acted on the exhaust valve, and held it closed if the normal speed was exceeded.

Three small engines of the usual four-cycle type, the manufacture of which has now been discontinued, are the **Werdau,** the **Januschek,** and the engine made by the **Sachsenburger Maschinen Fabrik.** A description of them will be found in the third edition.

A gas engine, vertical and horizontal, has been made for many years by **Baldwin Bechstein,** of Altenburg. It is a comparatively slow-running motor of the ordinary four-cycle type, and carries a slide valve for admitting the gas and air, and a flame for igniting the charge, worked from the crank shaft by geared wheels, 2 to 1, and a rod. The governor acts on the gas valve, and regulates the supply according to the load; the exhaust is driven from the auxiliary shaft. Another type has lift valves driven by gearing and hot-tube ignition; in most respects the engine resembles the Otto. In the vertical type the crank and connecting-rod are enclosed in a chamber filled with oil, which is picked up by the crank, and dashed over the working parts; in the horizontal engines centrifugal lubrication, with sight feeders to supply oil to the piston, is used. The Bechstein motors are fitted with a patented arrangement to show the quantity of oil used per stroke, thus enabling the consumption to be verified at any moment. The engine is made vertical from ½ to 3 H.P., horizontal from 2 to 20 H.P., and runs at 350 to 160 revolutions

per minute, according to size. It is also coupled to a suction gas producer (see p. 234).

Langensiepen.—Like many other German firms, Richard Langensiepen, of Magdeburg, has lately brought out a horizontal gas engine, to work chiefly with a suction gas producer of his own construction. The motor is of the usual four-cycle type, with valves driven by gearing from an auxiliary shaft. The governor acts on the hit-and-miss system in engines intended for ordinary work; for driving dynamos, the quantity of the charge is regulated, the composition of the mixture remaining the same. Ignition is by hot tube in engines worked with lighting gas, and by electricity where the motive power is furnished by suction producers. The engine is made vertical for 1 and 1½ H.P., horizontal from 2 to 125 H.P., and runs at 300 to 180 revolutions per minute.

The engine made by **Seck**, of Oberursel, and known as the "Gnome," is chiefly intended for use with petroleum, and a description will be found in the Oil Engine Section. It is now constructed also for gas, especially to work with a suction gas producer (see p. 234). A distinguishing characteristic is that the engine has no valve shaft, the valves being driven by eccentrics from the main shaft. Ignition is usually by a hot tube. As a gas engine the "Gnome" is made vertical only in sizes from ½ to 20 H.P., with a speed of 400 to 250 revolutions per minute.

Austrian Engines.—Bánki.—This engine is made on the Bánki and Csonka system, by Ganz & Cie., of Buda-Pesth, and is much used in Austria, especially when driven with oil, for agricultural and other industrial purposes. Several motors were shown at the Buda-Pesth Exhibition in 1896. The gas engines are of the ordinary four-cycle type, vertical only, and are similar to the Bánki oil engine, described in detail in Part II.; it is in fact the latter which has been adapted to work with lighting and power gas. The principle of water injections in the admission passage has been retained, but a double-seated automatic valve, to admit the gas and air, has been substituted for the oil pulveriser. The inertia governor, as in the oil engine, is on the valve shaft. If the normal speed is exceeded a lever is interposed below the exhaust valve-rod, and prevents its descent, while the admission valve is so connected to it that the governor holds the latter closed at the same time. The exhaust valve of this engine is driven by gearing from a cam shaft, and ignition is by hot tube without a timing valve. The engine is made for lighting gas in sizes from 5 to 50 H.P., and runs at a slightly lower speed than when driven with oil. The consumption is said to be about 15½ cubic feet of gas per B.H.P. hour.

A description of the Bánki gas hammer will be found in the Third Edition, p. 156.

Langen and Wolf, of Vienna and Buda-Pesth, make engines of the

ordinary four-cycle Otto type, with lift valves and hot-tube ignition. They claim to construct the "original Otto" engine with various improvements. Motors intended for driving dynamos are governed by varying the supply of gas. They are made in sizes from 1 to 125 H.P. with one cylinder, and up to 160 H.P. with two cylinders, and are also adapted for use with power gas.

Swiss Engines.—By far the largest and most important firm constructing engines in Switzerland is the **Schweizerische Maschinen-Fabrik,** at Winterthur, who exhibited several gas and oil engines at Geneva in 1896. They were all of the usual four-cycle type, with valves driven by gearing from the crank shaft through a counter shaft 2 to 1. Like many other Continental makers, this firm now build engines on a large scale, to work chiefly with Dowson and suction gas producers. So far these motors are all single-acting, although experiments with double-acting engines are now in progress. In a 50 H.P. engine, constructed for use with Dowson gas, the timing valve to the hot tube, the exhaust, and the starting gear are worked by cams from the valve shaft, the admission of gas and air by an eccentric on the same shaft. The governor acts upon this eccentric, and cuts off the admission earlier or later, according to the speed. The engine is started by compressed air introduced into the cylinder from a separate air reservoir, the exhaust being held open by a special cam, shifted or brought into play by a handle.

In their latest type of gas engine the speed is regulated by a rotary ball governor, driven from the auxiliary shaft. All the valves are contained in a valve chest which, together with the exhaust valve, is cooled by a separate circulation of water. The admission chamber has two double-seated valves, one for introducing the gas and air, the other regulates their admission to the cylinder. Both are opened at the same moment of the stroke, but their lift and time of closing are varied according to the load. The quality of the charge is not affected, but the governor acts on the volume, and therefore on the degree of compression. Expansion being the same, however reduced the volume of the charge, the pressure is lower if the load diminishes, and there is said to be less strain on the working parts. The exhaust valve is worked by a system of levers, the proportional lengths of which diminish the stress of lifting the heavy valve, and ensure its quiet action. Ignition is by electricity, and the engine is lubricated by automatic sight feeders and oil under pressure. The most important plant the firm have yet built is at the Embrach Potteries, near Winterthur, where there are three Dowson gas producers, three of their engines, each developing 100 H.P., and one of 40 H.P. The producers are placed below the floor of the engine-room, the hoppers to receive the fuel being on a level with the ground; drawing out the ashes and cleaning the fires take place in a basement space. All

the machines in the Potteries are driven by electricity furnished by the three 100 H.P. engines, the 40 H.P. engine supplies the electric light. They are started by compressed air from a small electric motor. Careful tests on this well-arranged plant determined the consumption at 0·87 lb. of fuel per B.H.P. hour. The Schweizerische Maschinen-Fabrik make horizontal engines with one cylinder from 2 to 150 H.P., with two cylinders up to 300 H.P., the speed varying from 240 to 150 revolutions per minute. With suction gas producers they claim to have achieved much success, and have hitherto supplied engines and plants from 20 to 50 H.P. They are now putting down a plant with three suction gas producers and three engines, each of 220 H.P., at Bilboa in Spain. Several hundreds of these producers are at work, with a total of nearly 3,500 H.P.

The **Actien Gesellschaft**, formerly MM. **Martini**, of Frauenfeld, make oil and gas engines of the Otto type, with hot-tube ignition, but since 1900 they have not built many. A small gas engine was exhibited at Geneva in 1896, in which the vertical valve shaft was at right angles to the axis of the crank shaft, from which it was driven by wheels 2 to 1. A cam on this shaft worked the gas valve through a rod, and if the normal speed was exceeded the ball governor on the top of the shaft shifted the rod, and the valve was not opened. The admission valve was automatic, the exhaust driven from an eccentric, and the products of combustion were discharged through the base.

MM. Escher, Wyss & Cie. also make gas engines of the ordinary four-cycle type, single cylinder, with hot-tube ignition and rotary ball governor. The valves are driven by cams from a side shaft geared to the crank shaft. The horizontal engines are in sizes from 2 to 60 H.P., and run at 250 to 180 revolutions per minute. In a new vertical type, the "Meteor," the crank and crank shaft are enclosed in a casing, to preserve them from dust. The engine is made from 1 to 12 H.P., and is said to work very quietly, in spite of a speed of 370 to 330 revolutions per minute.

CHAPTER X.

GAS PRODUCTION FOR MOTIVE POWER.

CONTENTS. — Gaseous Fuel — Natural Gas — Coal Gas — Distillation — Combustion—Water Gas—History—Dellwik System—Gas Producers—Bischof—Thomas and Laurent — Kirkham — Siemens — Pascal — Tessié du Motay — Strong — Lowe—Loomis—Chemical Processes.

THE first attempts to produce gas from coal were made as an experiment to obtain light, without any intention of utilising it as a motive force. The process of extraction was too costly for the gas to be employed to drive the motors invented at the beginning of last century, and many were the devices described by the patentees, to obtain a suitable explosive gas. In one of the earliest gas engines, brought out by Street in 1794, he proposed to generate a gas to act on a piston, by sprinkling a few drops of petroleum or turpentine on the bottom of a cylinder kept at a red heat. The liquid was evaporated, exploded, and drove up the piston. Barber obtained gas for driving his engine by heating coal, wood, &c., in a retort, according to the method now practised in gas works. The process of making gas was in its infancy, carried out only in large towns and cities, and there was much prejudice against it. It was also very dear. Practically in those days there was no gas to be had, and it was impossible to produce it cheaply, for driving small motors.

Gaseous Fuel.—As a fuel, however, coal gas was used long before its advantages as a motive force were perceived. During the first half of last century, as soon as the great value of steam was recognised, the economical use of coal became an important question. Without fuel, steam could not be generated, but although this is still usually done by burning coal under a boiler, it has long been known that it is rather wasteful. It is difficult by direct combustion to obtain temperatures as high as when gases previously extracted from the fuel are burnt. For chemical purposes, where great heat is required, gaseous fuel has been in use for many years. Cheap gas, made in producers or generators, is extensively employed in the manufacture of iron and steel, and other metallurgical processes, as being better and cheaper than burning the coal itself. A fresh stimulus was given to its production as soon as gas engines began to attract public notice and favour. It was seen that the maximum economy in driving them could never be attained as long as they were worked with town gas, and inventors have for more than a quarter of a century laboured to produce a cheaper and equally efficient gas. a

There are many ways of extracting gas from fuel. The composition of different gases will be found in Chapter xiv., and it is only necessary here to mention, without going into details, the methods by which it is obtained. These consist in bringing together, with or without combustion, the chemical constituents of the coal and air, carbon, oxygen, hydrogen, and their compounds. If the hot fuel is moistened with water or steam, the quantity of hydrogen is increased; if air be introduced, a much greater amount of oxygen is added. In either case the carbon in the fuel unites with the oxgyen of the air or of the water, and more carbon monoxide is produced than when the gas is formed from the chemical elements contained in the coal only. If the fuel is burnt in a closed vessel, and steam added and evaporated, the gas produced is richer in hydrogen than if air is admitted. When air is introduced, the same process takes place, but, instead of hydrogen being liberated, there is a large residuum of inert and useless nitrogen.

Gaseous fuel may be divided into six classes, namely:—I. Natural gas. II. Oil gas, obtained from petroleum, vegetable oil and refuse, shale, fat, resin, &c. III. Carburetted air, or air saturated with volatile spirit. IV. Gas extracted from coal, wood, peat, and other varieties of fuel, either by distillation, or with the addition of air or water. In the latter case it is called power gas, water gas, or producer gas. V. Blast-furnace gases, or gases generated during the production of pig iron from iron ore. VI. Coke-oven gases, or gases given off from coal when converted into coke for these furnaces. We will now proceed to consider generally the first four methods of gas-making; the two last have lately assumed such importance that their applications are treated in a separate chapter (Chap. xii.).

I. **Natural Gas.**—The process of generating gas from coal, or from the vegetable substances which form the basis of coal, is carried on by Nature as well as by man, though on an infinitely larger and more gradual scale. The gas is produced by the heat of the earth and the slow combustion of chemical decomposition. Gases exhaled from swamps and commonly known as "will o' the wisp" or marsh gas, are only a variety of lighting gas, which when artificially produced contains about 40 per cent. of marsh gas. As the decaying vegetation of swamps, bogs, and forests undergoes further decomposition or slow combustion, a fresh layer of soil is formed over it, and it passes very gradually during ages of time through the stages of peat, lignite, brown coal, and eventually to coal. Time, the earth's heat, decomposition and oxidation, and pressure frequently cause the escape into the atmosphere of the gases thus generated. Of this the disastrous explosions in mines afford an example. Marsh gas (usually termed "fire damp" or "choke damp") distilled, so to speak, from coal, and at a high pressure, and carbon monoxide, are

liberated by excavation, and rush into the mine workings, often with fatal consequences. When the gases find a natural outlet at the surface through fissures in the ground, as in many places in the United States, and in Russia along the shores of the Caspian Sea and elsewhere, they are given off from the earth harmlessly. This natural gas, consisting almost entirely of marsh gas, is of excellent quality for lighting and heating purposes, and contains more heat than artificially made gas. Formerly it was allowed to escape to waste, but it is now utilised, and furnishes much of the lighting gas in several towns of the United States, and is also extensively used to drive gas engines. For its composition, see Table, p. 300. Two trials on a three-cylinder, vertical, four-cycle 90 I.H.P. Westinghouse engine at Lafayette, U.S., will be found in the Tables. The consumption of natural gas was about 13 cubic feet per I.H.P. hour. Several other tests have also been made.

Natural gas has also been found in working quantities at Heathfield, in Sussex, and a considerable supply is believed to exist within a radius of 12 to 20 miles. The gas is of the following composition:—Methane, 93·4 per cent.; ethane, 3 per cent.; nitrogen, 2·7 per cent.; carbon monoxide, 0·9 per cent.; showing that it is almost pure marsh gas. It is found at a depth of 300 feet, and is of about 12 candle-power. It is used to light the railway station and part of the village, and also to drive gas engines, in which the consumption is from 13 to 15 cubic feet per B.H.P. hour, and a pressure of 134 to 200 lbs. per square inch is attained.

II. and III. The methods of producing gas from oil, and of charging air with petroleum or other spirit (carburetted air), will be described in the second part of this work.

IV. **Coal Gas.**—The gas used for lighting and heating is extracted from coal in two ways, either by—

1. Distillation, or the application of external heat to the coal.
2. Combustion, or actual ignition of the coal.

Distillation produces a much richer gas, and is the process universally used in gas works. The cheaper and inferior kinds of gas, such as water or producer gas, are obtained by combustion. These are employed as fuel instead of coal, and to drive gas engines. Professor Witz draws a further distinction between hot and cold distillation; the latter is chiefly employed for carburetted air.

1. **Distillation of Coal.**—The earliest method of obtaining gas from coal, first practised by Murdoch, was to heat the coal in closed retorts, and distil the gas from it. By this process the gases are given off, leaving a residuum of coke, &c. As the air is carefully excluded, the distilled products contain practically no gases except those already in the coal. Roughly speaking, two-thirds of the constituents are hydrogen, carbon, and their combinations. It is only of late years, since gas motors have

been made for larger powers, that the need of a cheap substitute for this distilled or town gas has been felt. As long as it was required only for illumination, the quantity used by each consumer was too small to make economy of production a relatively important question. As far as the heating value of town gas is concerned, it is well suited for driving a motor, but it is unnecessarily pure for this purpose, and the price per 1,000 cubic feet is relatively great. To produce town gas separately for driving small motors is, of course, impracticable, on account of the cost of production, &c. For some time, therefore, much attention has been paid to the production of a cheaper gas, less pure, but not liable to deposit carbon in the passages and ports of a motor.

2. **Combustion of Coal.**—The second method of manufacturing gas is by burning the coal, and three processes are employed, each producing a different kind of gas. In all of them, ordinary atmospheric air is required to assist combustion.

In the first process a forced air blast is used. The gases are rapidly generated by driving a current of air through the glowing coal, and combustion is thus stimulated. This furnishes what is called producer gas, and sometimes Siemens' gas, because it was first introduced by Sir William Siemens, as a fuel or substitute for solid coal. This gas is often used for heating purposes, but is not rich enough by itself to drive a gas motor.

In the next kind, known as water gas, the method followed is also to burn the coal or coke, and when it is a state of incandescence a jet of steam is injected into it. As a rule, water gas and producer gas are made alternately in the same apparatus. The third system is a combination of the two methods. Instead of alternately injecting steam and air into the mass of incandescent fuel, both are admitted simultaneously. The jet of steam carries with it into the fuel a current of air duly proportioned, and the gas, though poorer in quality, can be made continuously. Applications of this system are now very numerous. It was first brought out and patented in England about 1878-79, by Mr. J. E. Dowson, and another method was introduced into France by M. Lencauchez about 1887. Practically it is now used with all large gas engines, except those worked with blast-furnace or coke-oven gases. Engines driven with this cheap gas give from 10 to 20 per cent. less power for the same cylinder dimensions than when worked with lighting gas.

These three last kinds of gas—producer, water, and power gas—are usually made from anthracite or gas coke. If ordinary coal is used, the tar, ammonia, and other residual products are rather difficult to get rid of. Efforts are now, however, being made to utilise ordinary coal, and some of the modern producers make gas from poor, and even from bituminous coal. A distinguishing characteristic of these gases is that they contain a much larger quantity of carbon monoxide than lighting gas.

Carbon monoxide is highly poisonous, but has no smell, and care is needed, in using it, to prevent any escape.

Water Gas consists in theory of about equal parts by volume of carbon monoxide and hydrogen—namely, 50 per cent. H and 50 per cent. CO, or by weight 6·67 per cent. H and 93·33 per cent. CO. If the temperature be allowed to fall during the process of gas making, CO_2 will be formed. The gas is of great heating value, because of its large percentage of hydrogen. According to Naumann lighting gas contains only from 20 to 30 per cent. of the heat of the carbon in the coal from which it is made, producer gas 70 per cent., while water gas contains 92 per cent. It is, therefore, especially suitable for motive power, and when the difficulties of using it are overcome, it will probably be much employed for this purpose. When burnt it generates half as much heat as lighting gas, though costing very much less, and four times as much as producer gas, and it is not susceptible to cold or changes of pressure. The carburation of water gas is one of the latest developments in this branch of science. Sometimes, as in America and England, oil vapour is added to it, and the mixture is then combined with lighting gas. In Germany, France, and Belgium the same result is produced with benzol, a product obtained by distillation from bituminous coal.

In making water gas there are two successive stages. During the first, hot air is blown into the furnace to stimulate combustion; during the second, steam is passed through the column of coal or coke, previously brought by the air blast to a state of incandescence. While the water gas is being made, its composition is analysed from time to time, and, as soon as the percentage of CO_2 (of which there should be very little) exceeds a certain limit, gas making is stopped, and hot air again blown in. The plants are worked intermittently or continuously, and the gas made either in retorts, or by actual combustion in a generator; the latter is the more modern system. Anthracite, gas coke, or charcoal are used in the generators, and a high temperature is essential, as shown by the following table of experiments by Dr. Bunte (summarised from Geitel, *Das Wassergas*, &c., p. 15):—

TABLE OF VOLUME OF GASES AT DIFFERENT FURNACE TEMPERATURES.

Mean Temperature.	Composition of Water Gas Produced.			Steam.	
	Hydrogen, H.	Carbon Monoxide, CO.	Carbon Dioxide, CO_2.	Decomposed.	Not Decomposed.
Degrees C.	per cent.	per cent.	per cent.	per cent.	per cent.
674	65·2	4·9	29·8	8·8	91·2
861	59·9	18·1	21·9	48·2	51·8
1,125	50·9	48·5	0·6	99·4	0·6

Thus the higher the temperature in the generator, the better the quality, and larger the quantity of water gas produced.

The discovery of water gas is usually attributed to Fontana, in the middle of the eighteenth century, but the first working apparatus was invented by Donovan, in Dublin, in 1830. Carburetted water gas—that is, gas into which schist oil or tar was injected to render it luminous—was introduced by Jobard and improved by Selligues in 1834. From this time numerous patents were taken out in England and abroad. The gas was used for furnaces, but does not seem to have been applied to give light until 1865, at Narbonne, where it was manufactured by direct combustion in a furnace, instead of by distillation in a retort. The combustion of the fuel having first been stimulated by an air blast, steam was admitted until the temperature fell too low to make water gas, when air was again blown in. This intermittent process is known as the "blow and run" principle. In 1888 there were in Europe 24 water-gas generators, chiefly for non-luminous gas. At present about two-thirds of the gas works in America are said to produce water gas from nearly 300 generators, and it is increasingly used in England. Its carburation by means of naphtha has been applied to the improved Tessié du Motay-Wilkinson system in the Municipal Works at New York, and also to the Lowe process. These are the two types most used in America, although many others have been introduced. For further particulars as to the manufacture of water gas the original paper of Herr Geitel, *Das Wassergas und seine Verwendung in der Technik*, should be consulted. In this valuable treatise 58 producers are described, about 40 being illustrated with good drawings.

The main difficulty which long stood in the way of utilising water gas to any large extent was the simultaneous production of four times its amount of producer gas, necessitated by the process of manufacture. The problem how to get rid of the latter has been solved by carburating the water gas with oil vapour. The producer gas is led off into superheating chambers and burnt, and the heat thus furnished decomposes the oil by "cracking" it. Thus the process of water-gas manufacture now forms almost a perfect cycle of heat, as exemplified in the Lowe system, and still more completely in the Dellwik. If the gas is made intermittently, the large quantity of CO generated during the "blowing" process, owing to the deep layer of fuel and small quantity of air forced through it, causes a great loss of heat. In burning 1 lb. of carbon to CO, 2,400 calories are liberated, while if it be burnt to CO_2, 8,080 calories will be evolved, or 3·3 times as much heat. If producer gas containing a large proportion of CO be used to heat a vaporiser, and generate oil vapour, this heat will be utilised, but with non-carburetted water gas it is wasted.

The **Dellwik System** meets this difficulty. In it CO_2, instead of CO, is generated in the producer, and practically there is no producer gas as a bye-product. A much larger quantity of hot air is blown in at high pressure, and the layer of combustible kept very thin, with the result that only the ordinary products of combustion, CO_2 and N, both inert gases, are generated and discharged. As combustion is more complete, steam can be admitted and water gas produced for a much longer, and air blown in for a much shorter time, than with the ordinary system. Usually water gas is produced for about 15 minutes per hour, and hot air blown in for 45 minutes. In the Dellwik process the proportions are reversed, water gas is made for 45 minutes per hour, and its production is said to be doubled. From 1 ton of common gas coke Professor Vivian Lewes found that 70,000, instead of 34,400, cubic feet of water gas were produced. Steam being only admitted in small quantities at a time, there is no more CO_2 in the gas than before, and no excess of water vapour to oxidise the CO, and convert it into CO_2. The proper regulation of the quantities of steam and air is the main feature of the Dellwik system. In a six-hours' test at Warstein, in Westphalia, it was found that 1 kilo. of coke produced on an average 2·5 cubic metres of water gas, equal to a consumption of 25 to 30 lbs. of gas coke per 1,000 cubic feet of gas. The production per kilo. of carbon depended on the relative proportions of CO and CO_2. The heat utilisation, or the percentage of heat in the coke transferred to the water gas varies from 72 per cent. to 82 per cent., instead of some 40 per cent., as in other systems. In Germany, at Frankfort, and at the Königsberg Gas Works, there are large water-gas plants on the Dellwik system; the gas is produced for about 3d. per 1,000 cubic feet, but it is made on a large scale. The process is a good deal used in Germany, though in England it has hardly made much way at present. The composition of water gas will be found at p. 300; its average heating value is from 270 to 300 B.T.U. per cubic foot. It is the high proportion of poisonous CO which constitutes its chief danger; about 16 per cent. is the limit of safety.

Water gas has been used with good results to drive gas engines at Essen since 1891, when an Otto engine was started, and at Witkowitz Iron Works, where it has provided an aggregate of 223 H.P. To obtain the maximum pressure of explosion, and practically the same as in a gas engine, the percentage of water gas to air should be about 3 to 7, and an engine of the same dimensions gives from 10 per cent. to 15 per cent. less power than when driven with lighting gas. Herr Croissant, the director of the gas works at Ludwigshafen, in Germany, has drawn up a useful table, showing by calculation the heat efficiency of steam, lighting gas, Dowson, and water gas in engines of 100 H.P. to 50 H.P.,

taking the separate efficiency of the engine, the plant, and the two together, including heating up.

TABLE OF HEAT EFFICIENCIES IN ENGINES FOR STEAM AND DIFFERENT GASES AND FOR DIFFERENT POWERS.

Engine driven with	Heat Efficiency of Engine.			Heat Efficiency of Plant.			Heat Efficiency of Plant. including heating up.		
	100 H.P.	50 H.P.	10 H.P.	100 H.P.	50 H.P.	10 H.P.	100 H.P.	50 H.P.	10 H.P.
	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.	p. ct.
Steam, ...	12·5	8·3	4·0	8·8	5·8	2·8	6·9	4·6	2·2
Lighting gas (town), .	25·4	23·1	21·2	10·9	9·9	9·1	10·9	9·9	9·1
Dowson gas, ...	23·5	18·7	13·3	18·8	11·3	9·6	12·9	10·2	7·31
Water gas, ...	23·5	18·7	13·3	18·8	11·3	9·6	12·9	10·2	7·31

The great merit of water gas for motive power is its relative cheapness. When not carburetted it costs little more than power gas to produce, and is of far higher calorific value.

A series of interesting tests were made by Mr. Paterson, in 1898, at the Birkenhead Gas Works, on a 10 H.P. Crossley gas engine driven with (1) a mixture of equal parts of lighting and carburetted water gas; (2) pure carburetted water gas; (3) ordinary or non-carburetted water gas. The engine was not of the newest type. The following table shows the results obtained:—

TABLE OF CONSUMPTION AND HEATING VALUE, &c., OF THREE DIFFERENT GASES IN A CROSSLEY ENGINE.

Kind of Gas Used.	Consumption cubic feet of Gas per B.H.P. hour.	Heating Value B.T.U. per cubic ft.	B.H.P.	Heat Efficiency.
Town gas, ...	24·9	618·7	10·6	16·7 per cent.
Carburetted water gas, . .	27·6	568·3	11·16	16·3 ,,
Non-carburetted water gas, .	44·1	276·4	10·24	21·4 ,,

The heat efficiency of the water gas plant was 71 per cent.

Although much the cheapest, pure or "straight" water gas here gave the highest heat efficiency.

As made in England for power purposes by Messrs. Dempster & Co. of Manchester, the gas has a calorific value of 280 B.T.U. per cubic foot. It has been used to drive several engines, the consumption in which is from 30 to 32 cubic feet per B.H.P. hour. One engine has been worked with it for over twelve months, and two small engines driven with "blue" water gas have been running for some time at Ilford.

As the author was of opinion that there is a great future for this gas for power purposes, especially for driving large power gas engines, this detailed account of it is here given, although it has not been much applied in this direction. We pass to a description of different gas producers, marking the successive stages in their development.

Bischof.—The earliest attempts to obtain gas for heating purposes from the combustion of coal, instead of from distillation, were made by Bischof in 1839. Peat fuel was burnt in a brick chamber, air at atmospheric pressure was admitted from below, through holes in the covering of the ashpit, and the gases generated during combustion were drawn off through a chimney and damper from the top of the furnace chamber. In 1840 Ebelmen made a furnace for generating gases, worked by a blast of air, and a much larger quantity of gas was produced by this means than in Bischof's apparatus.

Thomas and Laurent.—But the merit of being the first to design a practical gas producer belongs to MM. Thomas and Laurent, who, between 1838 and 1841, constructed a gas generating furnace, in which many modern improvements were anticipated. Air compressed by a blower was admitted at the bottom of the furnace, and the decomposition of the air was assisted by the injection of superheated steam, in the proportion by weight of 35 parts of air to 1 of steam. The height of the generator was sufficient to cause the oxygen of the air to combine with the carbon of the fuel, and carbon monoxide and carbon dioxide were formed.

Kirkham.—Another remarkable apparatus was brought out in 1852 by Messrs. Kirkham, who, working independently but on the same lines as Thomas and Laurent, produced their gas by direct combustion of the fuel in a furnace, instead of by applying external heat to the coal, and distilling the gas from it. They were the first to use what is called the "intermittent" system of gas making—that is, the alternate admission of steam and air to the coal, and the gas was produced continuously. The fuel being kindled in the generator, a blast of air was turned into it, until combustion was thoroughly established; the air was then shut off, the producer gas blown off to waste, and steam was injected and quickly decomposed by the heat. After a short time the admission of steam was stopped, and air again introduced to revive combustion. Other gas producers were brought out by Ekmann in Sweden about 1845, Beaufumé in France in 1856, and Benson in 1869.

Siemens.—Several important gas producers were introduced with successive improvements by Sir W. Siemens, who gave his attention to the subject as early as 1861. His main object was to produce a gas which could be used as a substitute for ordinary fuel in furnaces, and he was the first to bring the question of gaseous fuel prominently

forward. In his producer a very slow draught of air and slow rate of combustion are employed, and the gases are cooled as they leave the generator. His designs have since been perfected, and the Siemens improved gas generator is now largely used for all sorts of metallurgical and manufacturing purposes. The two forms of gas producers introduced into France by Minary in 1868 and his later recent apparatus were invented with the same object of replacing solid fuel in furnaces. A useful little generator was brought out by Dr. Kidd in 1875, intended to provide a cheap gas for domestic use and cooking. With the exception of the Siemens apparatus these were all on a small scale, and none of them were originally intended to generate gas for working motors.

Pascal.—Pascal in 1861 was the first to develop the ideas of Thomas and Laurent, and those of Kirkham, and to test practically a system for manufacturing cheap gas, by the addition of steam and air to the incandescent fuel. Except in its application, his method differed little from theirs. A cylindrical gas generator filled with coal was surrounded by a boiler, with which it communicated. The coal was fired, and steam from the boiler admitted alternately with air from a blower, worked by the motor. Pascal's system of making gas has long been discontinued.

Tessié du Motay.—Another method brought out by Tessié du Motay in 1871 is still used, with improvements, in America at the Municipal Gas Works, New York. A brick furnace, enclosed in a wrought-iron cylindrical shell, is charged with fuel from above, and the gas drawn off through an annular space at the top. Air is introduced through a blast pipe running across the centre of the furnace, and the ashes and clinker are discharged below. To carburate the gas it is led through a chamber fitted with ledges, over which naphtha trickles down from above, is volatilised, and the vapour mixed with the water gas. It is then passed through red-hot retorts, to prevent condensation when the gas cools. This is said to be one of the best of the intermittent gas producers, and is simple and efficient.

These different generators exhibit the successive steps in the production of gas from coal. The first improvement on the process of distillation was the substitution of internal for external combustion. Instead of the outward application of heat to retorts, the fuel was burnt in the furnace, and the gas led off from it in pipes. A blast of air was next introduced, to accelerate the production of gas; the last and perhaps the most important innovation was the addition of a jet of steam. About 1862 two systems were proposed on the Continent for making water and generator gas. In the first, designed by M. Trébouillet, retorts filled with charcoal were brought to a red heat, and superheated steam forced through them. Charcoal was also used in the other method, invented by M. Arbos of Barcelona. The generator was in

two divisions. The upper part contained water, and formed a kind of boiler and superheater, and steam mixed with air was admitted at the bottom of the furnace. A modification of this process was applied to the Bénier generator.

Strong.—Two systems, both of American origin, the Strong and the Lowe, for making gas by admitting steam and air intermittently into burning fuel, were introduced about 1874. The Strong apparatus consisted of a generator filled with anthracite or coke, charged through a hopper above, or through doors at the side, and communicating with two heating chambers loosely stacked with firebricks. A forced blast of air was admitted both above and below the furnace, and produced active combustion, and the gases generated were driven into the first heating chamber. Here they were ignited by the current of air, and burned down through the firebricks and up through the second chamber, passing thence to the reservoir. As soon as the fuel in the furnace was at a red heat the air was shut off, steam introduced in the reverse direction to the air, and superheated in its passage through the red-hot firebrick. At the top of the furnace finely powdered fuel was sprinkled into it, the steam separated into its elements, and these combined with the carbon to form rich water gas. After a few minutes combustion slackened, and the process was reversed. A drawing of this producer will be found in the Third Edition, p. 168.

Lowe.—The Lowe process resembled the Strong in several respects, but contained a generator, a single superheating chamber, a carburator, and a scrubber for purifying the gases. The producer was worked intermittently. The generator being charged with anthracite, combustion was started by a blast of air. The hot gases given off were conveyed to the lower part of the superheater, where a fresh current of air kindled them, causing the flames to rise through the loosely stacked bricks. As soon as the generator was at a red heat, or at a temperature of about 1,600° F., the gases were discharged, the air was shut off, superheated steam blown into the furnace, and water gas generated. A small stream of petroleum was dropped from above on to the glowing fuel, and as the oil was "cracked" and vaporised by the heat, the gases were carburated. They were then purified by passing them through water and the scrubbing chamber.

Loomis.—An interesting example of the intermittent system of gas making, as applied to drive engines, is furnished by the Power and Mining Machinery Company of New York, makers of the Loomis generator. They have long used this gas to drive small engines, but have of late years constructed large plants to work engines especially for mining operations. A noteworthy feature is that the generator can be fired with any kind of fuel most plentiful in a given locality, anthracite, coke,

bituminous coal, or wood. The apparatus consists of two generators, with a small vertical tubular boiler between them. The generators are lined with firebrick, and are from 5 to 11 feet in diameter, and 12 to 18 feet high. Combustion is started by means of an exhaustor, which draws down a current of air through the glowing fuel in the generator. The producer gas thus formed is led upwards through the boiler, its heat converting the water in the tubes into steam, and thence to a gasholder. When the fuel is red hot, the air valve is closed and one generator shut off. Steam is then turned from the boiler into the other generator, and in its upward passage through it is converted into water gas, passes thence to the top of the other generator, downwards through the fuel, and up through the boiler to a scrubber, and finally led off to a gasholder. The processes of making water and producer gas are alternated every five minutes, more or less, according to the quality of gas desired. Thus the two generators are used to make producer gas, and only one or the other successively for water gas.

It is claimed for this system that, as all the gas is passed through the fire, the tar in it is converted into a fixed gas. By an ingenious contrivance, producer gas alone may be made in the generator, air being forced in by the exhauster as before, and steam admitted at various places to mingle with it. The change from one method of working to the other is easily effected by means of hydraulic valves. Water gas made by this process from bituminous coal has a heating value of 300 to 350 B.T.U. per cubic foot. For driving engines the two gases, producer and water, are led from their holders to a mixing valve, where they are combined in any desired proportions. The special characteristic of the producer, which makes it applicable in outlying districts remote from civilisation, is its adaptability to any kind of fuel. At Sonora, in Mexico, all the power required for working a large copper mine is furnished by electric motors. These are operated by eight four-cycle 110 H.P. gas engines, with a speed of 200 revolutions per minute, the gas for which is supplied by two Loomis generators, one in use, the other in reserve, each capable of yielding 1,000 H.P. The generator has two gasholders attached, the one for water gas, having a capacity of 5,000 cubic feet; the other for producer gas, of 15,000 cubic feet. The consumption in the generators is 1½ lbs. of inferior local coal, or 2½ lbs. wood per B.H.P. hour. At another mine in Mexico there are five 140 H.P. gas engines driven with Loomis gas made from wood. Elsewhere in Mexico there are various mines and mills worked with this power gas, which supplies a total of nearly 2,000 H.P. The generators are made in sizes from 50 H.P. upwards.

Chemical Processes.—The chemical process involved in making the two kinds of gas here described, producer and water gas, one or other of which is the basis of all power gas, is as follows:—Producer

Mean Composition in Percentage by Volume.	Name. Lower Heating Value.	Products obtained during Generation.
	Lighting Gas. 450 to 560 B.T.U. per cubic foot.	Ammonia, tarry products, benzol, coke.
	Coke-oven Gas. 340 to 560 B.T.U. per cubic foot.	Ammonia, tarry products, benzol, coke.
0-1 20-28 %	*Blast-furnace Gases.* 84 to 110 B.T.U. per cubic foot.	Pig iron, slack.
	Producer Gas. 124 to 146 B.T.U. per cubic foot.	..
	Mond Gas. 136 to 146 B.T.U. per cubic foot.	Sulphate of ammonia.

Fig. 96.—Diagram of Combustible Gases.

or Siemens gas consists of CO and N, and is formed by the incomplete combustion of the coal. The formula expressing it is $C + O = CO$. The carbon in the coal combines with the air to form a gas in the proportion of 35 per cent. CO to 65 per cent. N by volume. The theoretical heating value of this gas is 113 B.T.U. per cubic foot (1,015 cals. per c. metre). For water gas the formula is $C + H_2O = CO + 2H$. One lb. of carbon in the coal burns with 1·5 lbs. of H_2O to a gas of which the constituents are 50 per cent. by volume of CO, and 50 per cent. by volume of N. Its theoretical heating value is 303 B.T.U. per cubic foot (=2,710 cals. per c. metre). In the one case 1 lb. of carbon yields by combination with 73 cubic feet of air 88·3 cubic feet of producer gas; in the other, 1 lb. of carbon furnishes by combination with 1·5 lbs. of water vapour 61·4 cubic feet of water gas. The decomposition of the H_2O, however, in the latter requires more heat than is liberated by the formation of the CO. If the two processes be combined, as in Dowson gas, and steam and air injected together into a furnace, 2 lbs. of carbon will burn with 1·5 lbs. of water vapour and 73 cubic feet of air, producing 61·44 cubic feet of water gas, and 88·32 cubic feet of Siemens gas = 149·76 cubic feet of Dowson gas, in the proportions of 41 per cent. CO, 21 per cent. H, and 38 per cent. N. These values are theoretical, because in practice the oxygen and hydrocarbons cannot be wholly eliminated.

The diagram on page 200, showing graphically the composition of combustible gases, with their heating value and bye-products, is reproduced by kind permission of the Vereinigte Maschinen-Fabrik Augsburg and Maschinen-Bau Gesellschaft Nürnberg.

CHAPTER XI.

GAS PRODUCTION FOR MOTIVE POWER (*Continued*).

CONTENTS.—Modern Gas Producers—Dowson—Experiments—Bâle Trials—Tangye—Stockport—Fielding & Platt—Thwaite—Crossley—Paisley—Wilson—Duff—Mond—French Gas Producers, Lencauchez—Taylor—Pierson—Letombe—German Gas Producers, Deutz—Koerting—Nuremberg—Kappel—Bechstein—Oberursel—Langensiepen—Pintsch—Riché—Heat Efficiency.

IT is to Mr. J. E. Dowson that the merit belongs of having inaugurated the process by which superheated steam and air are admitted to a furnace together, to furnish power gas for driving engines. The gas obtained is poorer than water gas, but richer than producer gas; it can be rapidly and continuously generated, and with the proper admixture of air is perfectly suited for this purpose. It possesses the further advantage of being much cheaper than lighting gas. Before its introduction, it was considered impossible to work larger gas engines as economically as steam engines of about the same power. With few exceptions, only small motors were made, and, owing to the expense of town gas, it was supposed that large power gas engines could never compete successfully with steam. The adoption of Dowson gas first showed that it is possible to work a 100 H.P. gas engine with much greater economy in cost of fuel than a good 100 H.P. steam engine, and the fact that the larger the power, the greater the economy of consumption, has now been placed beyond a doubt. From this point of view, the pioneer services rendered by Mr. Dowson in making it possible to produce power more cheaply by the use of his gas are very great.

Modern Gas Producers may be divided into three classes, according to the pressure of air, whether above or below that of the atmosphere. There are two types of high-pressure producers, in which combustion takes place in a closed generator, and air charged with steam is either (*a*) drawn in by a steam jet, as in the Dowson, or (*b*) forced in by a fan. In the low-pressure system (*c*) the top of the generator is open, and air is drawn in from the atmosphere by the suction of the motor piston. Suction gas producers are now made by most of the chief firms in England and abroad. The principle is the same as that embodied in the Bénier, but the difficulties which hindered the development of the French generator have now been successfully overcome.

In these plants there is no gasholder or boiler, and the process of cleaning the gas is much simplified. A small chamber at the side of or above the generator or furnace is filled with water kept at a constant level, which is converted into steam by the heat of combustion. The suction of the engine piston during the admission stroke draws air charged with this steam into the bottom of the producer, and through the incandescent fuel with which it is filled. The gas thus generated is passed through a single coke scrubber, a gas expansion box, and thence to the engine, sometimes being also led through a hydraulic box to wash it, and prevent any escape back into the generator. The advantages of this system are that neither gasholder nor boiler are required, no escape of gas is possible, since it is produced below atmospheric pressure, and the engine itself automatically regulates the supply. Most of the modern types of gas producers, whether pressure or suction, dispense with a boiler, the heat of the gases of combustion, and of radiation from the furnace, being sufficient to provide steam to mix with the air. Hence a better heat utilisation is obtained, and the high temperature of the gases is employed in raising steam, instead of being wastefully lowered in an elaborate cooling apparatus. Efforts are now being made to adapt suction gas producers to marine work.

Dowson.—Fig. 96 shows an external view of a complete Dowson gas plant up to about 80 I.H.P. To start production, nothing is needed except anthracite or coke to fill the generator, and water to evaporate into steam for injection into the fuel. The steam pressure required is from 30 to 50 lbs. per square inch, according to the size of the gas plant to be served. The wrought-iron generator is seen on the left, and the small vertical boiler for producing the steam stands in the front to the right. The boiler has a closed grate, with steam pipes in the uptake, in which the steam is superheated, before it passes to the lower part of the generator. Between the boiler and generator is an injector, through which a current of air is forced by the velocity of the steam. The cylindrical generator is lined with firebrick, and the fuel is fed in preferably by hand through the hopper above; it varies in depth according to the combustible used. The gases generated by the combustion of the anthracite or coke combine with the oxygen derived from the decomposition of the steam and air, and are conveyed through a cooler and pipe into the hydraulic box, which is partly filled with water. The gases passing through the water are washed, and another pipe conveys them to the scrubbers, sometimes placed inside the gasholder, to economise space. One is filled with coke, continually moistened by water sprays; the gases pass from here into the second scrubber filled with sawdust, and thence to the holder.

To regulate automatically the production of gas the following method

is adopted:—The top of the holder is connected to a chain attached to the air injector. If too much gas is generated the holder rises, lifts this chain, and raises a valve from which the air and steam are allowed to

Fig. 96.—Dowson Gas Producer.

escape, instead of entering the generator. As soon as production is reduced, the holder sinks, and the valve is released.

Mr. Dowson has lately introduced an intermediate type of gas producer in which, in place of a boiler and steam jet, a fan sends the air to the furnace, and the heat of the latter generates the steam required. He has also brought out a suction gas plant, consisting of a generator with hopper and fuel admission valve at the top, a coke scrubber with water sprayed on to it from above, a small gas expansion box, and a hand fan for starting combustion. The generator consists of three parts, an outer lining through which the air for the furnace is passed, a chamber containing water converted into steam by the heat from the furnace and the hot gases, and the fuel chamber itself where combustion takes place. As the anthracite or coke is fed into the upper part of the generator, it is partially coked before it sinks down into the glowing zone of combustion. The greater part of the waste heat from the furnace is said to be thus utilised. The action of the generator after it is started is automatic, and as the pressure of the gas is less than that in the cylinder no escape is possible. The consumption in these suction gas plants is $1\frac{1}{4}$ lbs. coke or 1 lb. anthracite per B.H.P. hour. More than 200 are working in England, and 100 abroad. For a test of a National engine, worked in conjunction with a Dowson suction producer, see p. 210.

A large number of experiments have been undertaken with Dowson gas, and have proved its economy, and the relatively small cost of using it to drive engines. To make a proper comparison between a steam engine and a Dowson gas plant and motor, the cost of the fuel should in both cases be given, and the generator considered as forming part of the gas engine, in the same way as a boiler forms part of a steam plant. In England the gas can be produced at a cost of about 2d. to 3d. per 1,000 cubic feet, according to the quantity required, but in the case of large works, where a steam boiler already exists, the consumption of fuel can be reduced by utilising this steam for the generator. South Metropolitan London gas costs about 2s. 3d. per 1,000 cubic feet. Dowson gas is about four times less rich in heating value than town gas, and requires less air for its combustion in the cylinder of a gas engine. The actual charge admitted is no larger than when town gas is used, because the ratio of air is much smaller, being only from 1 to $1\frac{1}{2}$ times that of the gas. The proportional heating value of average coal gas, as compared with Dowson, is 3·8 to 1.

Dowson gas can only be made with coke or anthracite, but both are readily obtained in England. It is yearly becoming more widely known and generally used. It is easily produced; the plant is compact and simple, occupies a small space, and requires little attention; it does not burn with a smoky flame, and deposits no impurities in the ports and

valves of an engine. It can be made continuously, rapidly, and at a much lower cost than town gas. Most of the important firms in England and abroad now make engines for large powers, to be driven by Dowson or other producer gas. An account of these will be found under the head of the different engines.

Experiments.—Many trials with Dowson gas will be found in the tables at the end of the book. The Simplex engine was twice carefully experimented on by Professor Witz with Dowson gas. In 1890 he tested the 100 H.P. Simplex engine, shown at the Paris Exhibition, in which the consumption was 1·34 lbs. English anthracite per B.H.P. per hour. Dowson gas is used to drive the engines at Messrs. Crossley's works, and it furnishes a total of about 500 H.P. A good test of economy is the average working expenses throughout the year of large engines driven with this gas. In MM. Koerting's extensive engineering works near Hanover there are several engines driven by Dowson gas made in Koerting generators, with a total of about 400 H.P. At the Severn Tweed Co.'s Mills at Newtown, two trials, each extending over six days, were made upon four Crossley engines, driven with Dowson gas, and indicating a total of about 280 H.P. In the first trial anthracite was used and the total consumption was 1·23 lbs. per B.H.P. per hour. During the second the generator was fired with coke and 1·73 lbs. per B.H.P. per hour was burnt.

A good test was made by Tomlinson in 1891 on a 15 H.P. Atkinson Cycle engine, used to pump water from a well at the Uxbridge Waterworks. The engine was coupled direct to double-acting pumps 80 feet below the surface, and was driven at 86 revolutions per minute. The total quantity of fuel used was 1·06 lbs. per I.H.P. per hour, or 1·48 lbs. per water horse-power per hour; and about 16·4 per cent. of the heat units in the fuel were converted into total work, or 12 per cent. into water pumped. Another trial was made in 1892 by Mr. Dowson on a Crossley-Otto engine developing a mean of 118·7 I.H.P. The fuel consumed during the trial was 0·76 lb. per I.H.P. per hour, including anthracite for the generator and coke for the boiler. This trial was at Messrs. Mead & Co.'s Flour Mills, Chelsea. Some useful trials to test the variations in the calorific value of Dowson gas during the process of generation were made by Mr. Paterson at Liverpool, and showed a considerable difference, according to the time which had elapsed since the last clinkering. This process only took place once in 48 hours. Ten hours after clinkering the heating value of the gas was 149·2 B.T.U. per cubic foot; 26 hours after clinkering it was 141·3 B.T.U. per cubic foot; and 48 hours after, or just before a removal of the clinker, the heating value fell to 113·6 B.T.U. per cubic foot.

An interesting series of experiments was made in 1895 on two 50

H.P. Crossley-Otto engines driven with Dowson gas, providing electricity for the Mountain Railway at Zurich. Each engine has a gas generator attached, and one engine and generator were used to drive the dynamos, the other as a reserve. The ignition tube was heated by a flame fed with Dowson gas, and one boiler furnished the steam to both generators, if required. Each generator produced 10,593 cubic feet of gas per hour, or sufficient to develop 120 H.P. Two experiments were made to determine the efficiency of the engines under normal working conditions, and a third for the maximum power. The mean heating value of the gas, taken constantly with a Junkers calorimeter, was 144 B.T.U. per cubic foot, but it was found to vary greatly from hour to hour, depending more or less upon the quantity of coal, time of stoking, and power required. The total consumption of Belgian anthracite for the generator and boiler was 1·4 lbs. per B.H.P. per hour; the mechanical efficiency at maximum power was about 90 per cent. Full details of this excellent trial will be found in the *Zeitschrift des Vereines deutscher Ingénieure*, Dec. 21 and 28, 1895.

One of the most complete trials was carried out at the Bâle Water Works, in 1896, by Professor Meyer, one of the best authorities on the subject of power gas. He tested a 160 B.H.P. Deutz-Otto gas engine, with two cylinders. The pistons worked on to the same crank and drove three pumps, each 10·2 inches diameter, and 2 feet 3½ inches stroke, the brake H.P. being determined from the work of the pumps. Indicator diagrams were taken every five minutes, the temperature of the superheated steam was noted, and also that of the steam and air below the jet, as well as the cooling water, in and out of the jacket.

The experiment, lasting ten hours, had for its object to determine the quality of the gas, and the chemical changes during the process of generation, and it forms one of the most careful studies of Dowson gas which has yet appeared. The plant consisted of three generators, two small steam boilers, two sawdust purifiers, and four scrubbers, but during the trial only one generator and boiler were in use. The fuel burnt was gas coke made from German coal; it had a heating value of 12,960 B.T.U. per lb., and contained 87·7 per cent. carbon and 9·7 per cent. ash. As regular quantities were fed in by hand every ten minutes, the heating value of the gas did not vary as much as in the Zurich trials. About 35 cubic feet of water per I.H.P. hour were required for the generator, scrubbers, and the cooling jacket. Samples of the gas taken every hour, and analysed by Hempel's process, gave by volume 4·8 per cent. CO_2, 27·6 per cent. CO, 2·0 per cent. CH_4, 7 per cent. H, and 58·6 per cent. N. The heating value determined every 10 to 15 minutes in a Junkers calorimeter, and corrected for temperature and pressure, was 135 B.T.U. per cubic foot. Consumption of coke 1·4 lbs. per I.H.P., and

1·6 lbs. per B.H.P. hour, and 1 lb. of coke yielded 75·8 cubic feet of gas at 0° C. and 760 mm. pressure. Of the total heat in the coke 95·7 per cent. was developed in the generator, and 4·3 per cent. lost while pass-

Fig. 97.- Dowson Gas Plant at Walthamstow. 1904.

ing through the boiler; 71·3 per cent. was available for the engine, making the loss to the generator 24·4 per cent. Heat efficiency of the gas engine 19·3 per cent. per B.H.P.

During the trial 54 per cent. of the steam sent to the generator was decomposed, and 46 per cent. passed through it unchanged, causing waste of heat, and lowering the temperature in the generator. To

Fig. 97*a*.—Dowson Gas Plant at Walthamstow—Scrubbers.

account for this, experiments were made working the engine at the same power, with gas from one and from two generators. Probably the loss of heat to the steam was caused by the varying temperature in the

generator, which was much hotter at the bottom than at the top. Immediately after stoking it fell 50°, and rose again 50° three minutes later. Hence the intermittent calorific value of power gas, which has so often been noticed. According to Professor Meyer, the gas produced always leaves the strata of the generator, in which the chemical processes take place, at the same temperature, and becomes cooled by passing through the upper layers of freshly stoked combustible. The exchanges of heat between the gas and the coke can be calculated, and the loss by incomplete decomposition of the steam determined.

When working with two generators the coke consumption was 17 per cent. more than with one, and as the power developed in the engine was practically the same, this 17 per cent. of heat was wasted—that is, it passed through the generators without being converted into work, and 21 per cent. of the total steam supplied was not decomposed to a gaseous condition. The temperature of the discharge gases was also higher when working with one than with two generators. Thus it was evident that the hotter the generator, the more steam was decomposed. The low heat efficiency was attributed to the poor quality of the gas made from coke, which was difficult to treat, although the charge was fired electrically. It burned slowly, and ignition lasted almost to the middle of the stroke, as was shown by the form of the indicator diagram. The engine was of rather an old type, but when run at a higher speed, all other conditions being the same, the pressure of explosion and the efficiency were increased. Had this higher speed been maintained throughout the trials, the consumption would have been 1·1 lbs. per I.H.P. hour, and the heat efficiency 23·8 per cent.

Two important modern installations of Dowson gas are at the Walthamstow Electric Station, which is worked by four Westinghouse engines developing a total of 1,650 H.P., and at the Birmingham Small Arms Factory, where 1,500 H.P. are supplied for electric lighting, also from Westinghouse engines worked with Dowson gas. The consumption in both cases is about 1 lb. anthracite per B.H.P. hour. Figs. 97 and 97*a* show the generator at Walthamstow. An interesting trial, one of the first of its kind, was made on a Dowson suction gas plant serving a 40 B.H.P. National engine, in which the average calorific value of the gas was 148 B.T.U. per cubic foot, and the heat efficiency of the plant about 90 per cent. (See Table No. 6.) Dowson gas now furnishes 32,500 H.P. in England, and nearly 9,000 H.P. abroad.

Tangye.—Like most of the modern generators, this gas producer is practically automatic in action. The two improvements claimed for it are the effective feeding of the fuel into the generator without allowing the height of the fire, and hence the quality of the gas, to vary, and the careful treatment of the gas after it leaves the furnace. If steam

is not available, a small separate boiler is required, and both the steam and air are superheated before entering the furnace, thus ensuring their rapid decomposition into gas. A drawing of this gas plant will be found in the third edition. It consists of a conical hopper with valve above, which holds enough fuel to last for several hours, and a generator below, lined with firebrick. The gases are led off through a wide pipe with two passages, through the lower of which they pass to a box, where they are freed from dust. In this passage is a U-shaped tube, into which the steam from the boiler is drawn and superheated by the gases, and thence carried off and mixed with air in the proper proportions for com-

Fig. 98.—Tangye Suction Gas Producer.

bustion. The two pass to the hearth through an annular passage in the lining of the generator. The gases are led off down the centre of the cooler to the dust box, and thence to the hydraulic box, where they pass upwards through loosely-stacked coke, moistened by water continually playing on it from above. After drying, they are finally led to the gas-holder. The gas produced has a heating value of about 160 B.T.U per cubic foot, and the plant is said to generate 168,000 cubic feet per ton of Welsh anthracite. It can only be worked with anthracite or coke.

Messrs. Tangye have lately introduced an improved suction gas producer (see Fig. 98). Like the producer described above, it has a

charging hopper and generator, but neither boiler nor gasholder, the latter being replaced by a small chamber above the furnace, filled with water. The suction (admission) stroke of the engine draws air through this chamber, where it is charged with hot vapour, and the two pass downwards outside the furnace, as shown, and up through the incandescent fuel, being converted into gas in their passage. The gases are next conveyed in the direction of the arrows to the scrubber filled with coke moistened by water running through it, and thence to the engine. Suitable arrangements are made for draining the scrubber and keeping the level of water in the vapour chamber constant. The furnace is started by means of a small fan worked by hand. Engines driven with this suction producer are made from 7 to 88 B.H.P., with electric ignition and high compression of the charge.

Stockport.—A suction gas producer is also made by Messrs. Andrew, of Stockport, on a similar principle to the Tangye—namely, that of manufacturing the gas per stroke, as required. The fire in the generator is started by a small blower. As soon as the fuel is thoroughly alight, the suction stroke of the engine draws water into a vaporiser, where it is converted into steam, and passes, together with a certain quantity of air, to the bottom of the furnace. The two are drawn through the incandescent fuel to the coke scrubber, on to which water is played from above, thence to a small reservoir, and lastly to the admission valve of the engine. The consumption is about 1 lb. anthracite, or 1½ lbs. coke per B.H.P. hour.

A similar suction gas plant is made by the **National Gas Engine Company.**

Fielding & Platt.—A generator on the Dowson system is constructed by Messrs. Fielding & Platt, of Gloucester, to work with their engines. They have also, like other firms, introduced a suction gas plant, in which the gas is produced as required. Water and air are drawn through the furnace, and the gas through the coke scrubber by the action of the motor piston itself. More than a hundred engines have been made to work with this type of producer.

Thwaite.—Another gas-making plant has been introduced by Mr. Thwaite to produce gas not only from anthracite and coke, but also, it is said, from bituminous coal, slack, breeze, sawdust, peat, &c. Drawings of the plant will be found in *The Engineer*, July 5, 1895, with a description of a generator erected in the North of London for driving a gas plant to produce electric light. No trials seem to have been published.

Crossley.—Messrs. Crossley have also introduced new types of pressure and suction gas producers. In these there is no boiler; the heat of the gases from the producer is utilised to generate steam in the saturator, an annular vessel consisting of an inner and outer pipe. The

space between the two is filled with water up to a certain level, while the hot gases from the generator are led through the inner pipe. The action of the producer is started by drawing air, preferably from a fan, across the top of the saturator. Here it is charged with steam, and the two pass down through the outer lining of the generator, and upwards through the fuel. The gas thus formed is led down through the centre of the saturator, and by imparting its heat to the water is cooled as it reaches the bottom. From hence it passes through a hydraulic box to the coke and sawdust scrubbers, in which it is washed and cleansed before entering the engine. The hydraulic box acts as a water joint, to prevent gas passing backwards, and frees it from the dirt, which is washed out into an inclined water trough. The grate can be rotated, and the ashes and clinker withdrawn while combustion is proceeding. This plant may be worked either under pressure or by suction; in the former case a small fan is necessary, generally driven from the engine itself. It is made in sizes from 60 to 250 B.H.P.

If the suction of the engine piston be used to generate the gas, the water chamber is usually placed at the top of, or round the generator, and the scrubbers are reduced in number; thus the area required for cooling the gases is much diminished. Suction gas plants are made by Messrs. Crossley from 5 to 80 H.P., and the consumption in them is about $\frac{3}{4}$ to 1 lb. anthracite per B.H.P. hour. Like the Deutz firm (see p. 230), they also construct a producer to work with bituminous slack. It consists of a generator and saturator, a washing and cooling tower, a patent centrifugal tar extractor, and a sawdust scrubber. The gas leaving the producer is said to be perfectly clean. These plants are made on a large scale, for engines from 150 to 1,000 H.P. A small steam engine is required to drive the blower, the tar extractor, and a centrifugal pump to circulate the water for washing the gas.

A gas producer of the usual type, with boiler and steam injections, was brought out some years ago by Messrs. **Paisley & Welch**, in which the boiler was fed from a water tank heated by the generator. The gases were twice carried through the furnace, and thence led successively through three coolers and a coke scrubber to the gasholder. The average calorific value of the gas was 158 B.T.U. per cubic foot, but the producer does not seem to have held its place in the market. In a test made on a plant supplying gas to two 50 H.P. Stockport engines, the consumption was 0·65 lb. anthracite for the generator, and 0·22 lb. coal for the boiler per B.H.P. hour. Bituminous coal could not be burnt in this producer.

The **Wilson** producer was not originally intended to generate gas for driving a motor, but since the great development in this direction it has been adapted to the purpose. It has neither grate nor bars, the fuel

resting in a solid mass 6 to 10 feet high upon the hearth itself. The producer consists of a cast-iron cupola-shaped furnace, into which the combustible is charged through a bell and hopper; a slide prevents any escape of gas during the operation. In the centre of the furnace at the bottom is a kind of box with openings, through which the air and steam are drawn in. The steam, generated in a separate boiler, enters through an injector, and carries air with it, in the proportion of about 20 parts of air to 1 of steam, into a central vertical tuyere, and thence the two are forced into the fuel to decompose it. They are delivered centrally, as far as possible from the sides, in order that they may be thoroughly mixed. A mass of glowing combustible is soon started round the tuyere, and as this reacts upon the steam and air, the heat decomposes them. They are said to keep the tuyere relatively cool, so that it does not burn. Hydrogen and carbon monoxide are formed, and escape upwards, while the superincumbent fuel sinks gradually down. As it has already been partially distilled while still in the upper part of the furnace, the liberated hydrocarbons mix with the ascending H and CO, and are led off through openings at the top. The bottom of the producer rests on a water seal, to prevent the escape of any gas below. As the hot ashes sink into the water more steam is generated, ascends through the fuel, and increases the small quantity of steam already produced. The clinker and ash are removed automatically by a screw below the water-line, revolving slowly and continuously. As the fuel is kept slightly moving, the clinker does not adhere. It is mechanically discharged along an inclined plane, as shown. From the producer the gases, at a temperature of nearly 1,000° F., are led to the regenerator, an arrangement of vertical pipes in an air-tight casing, similar to the well-known Green's economiser. Air at a maximum pressure of 8 inches of water is forced by blowers into the pipes of the regenerator, while the hot gases from the producer circulate round them, transferring much of their heat to the air in its passage. Sometimes water is admitted into some of the pipes. The air and gases enter the regenerator at opposite ends, on the principle of contrary currents. The gases are then further cooled in a dry cooler, and do not reach the washers till they have been reduced to atmospheric temperature. Here all traces of tar and dust are eliminated, and they are then led, sometimes through a sawdust scrubber, to the gas holder. The blowers are driven by a small steam or gas engine.

The Wilson producer is shown in section at Fig. 99. Its heating value was calculated by Mr. Stead at about 150 B.T.U. per cubic foot, and in an engine cylinder the gas yields about 1 H.P. per lb. of bituminous slack burnt. For this kind of coal it has been specially designed. The producer has been supplied to over 100 manufacturing firms in England. One of the most important installations is

Horsehay Works, Shropshire, where a Wilson producer, with a capacity of 300 H.P., supplies power gas to drive two 80 H.P. Stockport and several smaller Crossley engines.

The **Duff** producer, made by Messrs. W. F. Mason, of Manchester, is another successful attempt to utilise bituminous slack to generate power gas, and to eliminate the volatile tarry substances which cause so much difficulty in an engine cylinder. As in some other producers, part of the gases are twice passed through the furnace. The generator consists

Fig. 99.—Wilson Gas Producer.

of an inclined grate, forming a ridge in the centre of the furnace, and pierced with slots to admit air. The casing is lined with firebrick, and rests on a trough filled with water, which acts as a seal; the top is arranged as a charging platform. The gases rise up through the mass of glowing fuel, and pass through flues to the wide gas main at the top, but the tarry vapours are carried off through orifices in the upper part of the producer to two downcast pipes. Here they are met by a jet of steam and forced into the bottom of the furnace, where the steam is decomposed, and forms hydrogen and carbon monoxide by combining with the carbon in

the tar. No air being required for this second process, the percentage of nitrogen in the gas is relatively small. The air is delivered to the bottom of the generator by a Root's blower, the steam for which is drawn from the small boiler supplying the steam jets.

A 500 H.P. Duff plant has been lately supplied to a company in London, and provides all the power and heating required in their works. The producer is of the type already described; the boiler furnishes steam at 40 lbs. per square inch pressure. From the generator the gas is led to the cooling tower, and the makers assert that, when the plant is worked at full load, the waste heat of the gases in this tower will suffice to raise all the steam required. It is then passed successively through five condensers, a coke scrubber, and a washer, to the holder, and finally through a sawdust scrubber, after which it is said to be perfectly clean. It has a heating value of 150 B.T.U. per cubic foot, and an average chemical composition of CO_2 4·2 per cent., CO 25·2 per cent., H 22·6 per cent., CH_4, &c., 4 per cent., N 44 per cent. The Duff producer is made by Messrs. Mason for power and heating purposes; the right to work it, with recovery of the ammonia, has been acquired by the Power Gas Corporation Company, the holders of the Mond patents.

Mond Producer.—In making lighting gas from coal distilled in closed retorts, the gases are withdrawn, and non-volatile carbon remains as coke. In power gas, practically all the carbon is converted into gas, and the volume of gases obtained from a given weight of coal is greatly increased, but for years it was found impossible to obtain a clean gas, free from tar, except with anthracite or coke as fuel. Usually no attention is paid to the recovery of the bye-products, and most generators are worked at so high a temperature that the ammonia formed during gasification is destroyed.

These disadvantages are overcome in the producer designed by **Dr. Mond,** and it is one of the most successful which has yet appeared, but the gas requires to be made on a large scale, and a plentiful supply of water is necessary. The objects aimed at are to utilise the cheapest bituminous small coal and slack, and to recover the ammonia in the gas, as much as 90 lbs. of sulphate of ammonia being now obtained per ton of fuel burnt, or 70 per cent. of the nitrogen in the coal. A ton of cheap slack yields from 130,000 to 160,000 cubic feet of gas. These results are obtained by introducing a large quantity of steam, more than double the weight of coal, into the generator; it is thus kept at an equal and low temperature, the coal does not cake, no clinker is formed, and there are very few tarry deposits. The fuel is fed in mechanically in quantities of 8 to 10 cwts. at a time, and uniformity in the composition of the gas is said to be secured by the air blast saturated with steam. Another advantage is that the generator is fed with common bituminous slack,

and even with a partially caking coal. This may be said to be at present the great desideratum in all gas producers, and if cheap common slack can be burnt in them, they will probably be generally adopted for large powers and constant work. The ammonium sulphate forms, as is well known, the best possible manure.

The essence of the Mond process is gasification at a low temperature, and utilisation of the heat developed in a regenerator. At the large plant in use at Messrs. Brunner & Mond's works at Northwich, England, the coal is delivered from a hopper into a coal creeper with suitable openings above the row of producers (see Fig. 100). Each producer burns 1 ton of slack per hour, and is served automatically with sufficient combustible for the day. It consists of a double wrought-iron shell, cylindrical above and cone-shaped below, partly lined with firebrick, the whole being supported over a water seal, into which the outer shell projects. The inclined fire bars forming the grate rest upon a circular casting running round the bottom of the shell. At the top is a bell-shaped vessel, into which the slack is first fed, partly distilled by the hot furnace gases, and the tar in it converted into a fixed gas as it passes downwards. The ashes fall through the circular grate and form a cone extending to the water seal, and the fresh combustible rests partly upon them. After being drawn through the regenerator, the air for combustion and steam enter the shell at the top, are forced down through the jacket formed by the double cylindrical lining of the producer, and, after being thus twice heated, pass into the grate from below. It is on their contact with the burning fuel that the chemical

Fig. 100.—Mond Gas Producer.

changes take place. The carbon burns to CO and CO_2, and the heat decomposes most of the steam, liberates a large quantity of hydrogen, and also sets oxygen free to combine with the carbon.

The gas thus obtained is first led off to the regenerator, consisting of two concentric vertical wrought-iron tubes, one within the other, which constitutes one of the principal features of the apparatus. The air and steam blast are led through the outer pipe on their way to the producer, while the generator gas passes in the contrary direction through the inner, and an exchange of heat takes place. The gas at a temperature of about 280° C. is next passed through a washing chamber, where water is sprayed into it, the gas is cooled and cleansed, and steam is formed at a temperature of about 90° C. The mixture then enters the "acid tower," where the ammonia is withdrawn in the usual way, by means of acid liquor containing 4 per cent. of free sulphuric acid. The solution of sulphate of ammonia is circulated again and again through the tower till it has attained a strength of 36 to 38 per cent. The gases are led thence to the base of a cooling tower 12 feet in diameter, where they are met by a current of cold water, the steam is condensed, and the temperature of the gas rapidly reduced. Thus cleansed, cooled, and freed from ammonia, it is led off to the gas mains. As the cold water entering at the top of the tower becomes hot in its descent, it is pumped, on reaching the bottom, to the top of another tower, through which the air for the producer blast is blown; the one is heated and charged with vapour, and the other cooled. A double ram pump serves the two-fold purpose of sending on this cold water, and the hot water to heat the air; the latter being supplied by a blower, the gas is always under pressure. Two and a half tons of steam per ton of fuel are required if the ammonia is recovered; where this is not done, 1 ton of steam suffices. For every ton of coal treated, 1 ton of steam is admitted to the producer with the air, the remaining 1½ tons are usually taken from the exhaust of steam engines and pumps, if such are available. Much of this steam is not decomposed, but condensed, on leaving the producer, and its latent heat continuously utilised. About one million cubic feet of this gas are used per hour in the works at Northwich. The process is elaborate, but forms almost a complete cycle of heat, very little being allowed to escape. The circulating water acts as the heat agent between the hot gases and the cold air. One set of towers will treat the gas from six producers. The first circular producer was started in 1893 at the Brunner & Mond Chemical Works at Winnington, near Northwich, Cheshire, and has since been working successfully. For power purposes, Mond gas was first used at the Electric Station at Northwich in 1894. The efficiency of the system of regeneration is said to be high. The gas has a heating value of 145·6 B.T.U. per cubic foot saturated, and of 156 B.T.U. dry, at

32° F. It is said to contain 80 per cent. of the heating value of the fuel used, which, according to the inventor, is a higher heat efficiency than is obtained with other producers.

A peculiarity of Mond gas is the large excess of air required, and high percentage of CO_2 produced, but the latter is said to be counterbalanced by the amount of hydrogen present. Its chemical analysis will be found at p. 300. The gas may be utilised in the same way as blast-furnace gases, and burnt in gas engines to drive dynamos for a central power station. The recovery of the sulphate of ammonia alone, if worked on a large scale, and if about 20 tons of slack per day are treated, is said to be sufficient to cover the cost of the fuel. The plant is rather complicated, but if properly worked, and a good price is obtainable for the bye-products, it may be said to give power for practically nothing. To utilise bituminous coal, containing 30 per cent. of volatile matter, for the production of gas, is a much needed improvement. Like a blast furnace, the Mond producer, with its extensive recuperation of heat, is specially suited to the generation and transmission of electrical energy on a large scale. The exhaust heat can now be utilised to generate all the steam required in the Mond process. The gases discharged from the gas engine are passed through a small tubular boiler in which their heat raises the steam. An economy of 20 per cent. of fuel is said to be thus realised.

A trial of this gas with a Crossley engine was made by Mr. Humphrey in 1894. The thermal efficiency was 23·8 per cent. per I.H.P.; heat efficiency of the generator 80 per cent. The engine drove a dynamo at a speed of 191 revolutions per minute. Common slack was burnt, and yielded 160,000 cubic feet of gas per ton. Details of the trial will be found in the tables of power gas. The average calorific value of the gas taken in a Junkers calorimeter was 155 B.T.U. per cubic foot. A Crossley-Otto two-cylinder 150 H.P. engine, worked with Mond gas to drive a dynamo direct, was erected some years ago. During a trial of this engine in 1897 the speed was 162 revolutions per minute, consumption of gas 65 cubic feet per I.H.P. hour, and of slack 0·92 lb. per I.H.P. hour. The heat efficiency was 26·8 per cent. per I.H.P., mechanical efficiency 83 per cent., while the total efficiency, or ratio of useful electrical H.P. to total I.H.P. developed, was 72·7 per cent. In 1898 it was tested for continuous work. At 90 per cent. of the full load it ran without stopping night and day for three months, whereas with town gas the valves require cleaning, and the engine must be stopped, once a fortnight. During the run the average thermal efficiency was 25·5 per cent. The engine also ran 139 days consecutively without a hitch, from January to June, 1899, thus showing the great purity of the gas. Another trial, particulars of which will be found in the Tables, was made on a 500 H.P. Premier

"scavenging" engine, in which a heat efficiency of 34 per cent. per I.H.P., and 25·5 per cent. per B.H.P. (lower heating value) was obtained. The plant at Northwich burns 1 ton of fuel per hour, yielding from 130,000 to 160,000 cubic feet of gas, equal to 3,000 H.P. The average consumption is about 1¼ lbs. of slack per electrical H.P., or 1 lb. per B.H.P. In engines developing up to 650 H.P. the consumption is about 60 cubic feet of Mond gas per B.H.P. hour. If part of the steam is raised in a separate boiler, the H.P. per ton of slack will be reduced to 1,500 per hour. The power required to drive the blower, pumps, dashers, elevators, coal-handling machinery, &c., is 1 H.P. per ton of slack, or 1½

Fig. 101.—Mond Gas Plant at Warrington.

per cent. of the gas generated, if used to drive an engine. As regards the cost of working, if a good price can be obtained for the sulphur, say £8 10s. per ton, and the slack coal can be bought for 3s. a ton, the cost of the one will cover the other, including the working expenses.

To meet the demand for power engines, smaller producers have been designed from 250 H.P. upwards, burning only 5 tons of slack per twenty-four hours. In these the ammonia recovery towers are omitted, and the

construction simplified. Less steam is required, and sufficient can be raised entirely from the exhaust of the gas engine.

In these smaller, as in the larger, plants the composition of the gas remains constant. A 1,000 H.P. installation of this kind has been put down at the Premier Gas Engine Works, and another of 500 H.P. to work with Westinghouse engines at the Cadbury Works, Birmingham. Fig. 101 gives a view of a plant at Warrington, showing the producers and generators. The Power Gas Corporation, who have taken over Messrs. Brunner & Mond's patents, and also the Duff (see p. 216), now gasify 250 tons of slack daily, yielding 37,000,000 cubic feet of gas. No other heat or power agent is used in their works, and they also supply gas to drive three 100 H.P. Crossley engines, which furnish the power to light the town of Northwich with electricity. Mond gas is now (1905) used to develop nearly 40,000 H.P. For further particulars of this interesting system see *Proceedings of the Institution of Civil Engineers*, vol. cxxix., p. 190, where drawings of the original large plant will be found.

French Gas Producers—Lencauchez.—This system is much used for making gas in France. It was invented by M. Lencauchez, and the apparatus being first made at the Chantiers de la Buire, Lyons, it was originally called the Buire-Lencauchez system. In outward appearance the generator differs little from the Lowe, but the gas is continuously produced. It was adopted by MM. Delamare-Deboutteville and Malandin, the inventors of the Simplex engine, and is still utilised, a Lencauchez gas producer being added to many of the Simplex and other French engines. It is also applied to drive Otto engines, made by the Compagnie Française.

Fig. 102 shows an elevation and Fig. 103 a plan of the improved apparatus by M. J. A. Lencauchez, son of the inventor. A is the valve for admitting and regulating the supply of air, B is the blower worked from the small gas engine E, C C are two chimneys. At G are seen the producers, of which there are two in this plant; between their firebrick lining and outer iron casing is a layer of sand. S is the scrubber filled with coke, from whence the gases pass to the purifier P through the tar condenser T. The fuel is charged by hand through a hopper above the furnace, and the clinkers and ashes are withdrawn once in twenty-four hours. A current of air, sometimes heated by the hot gases from the generator, is sent into the latter from the fan or blower. A small stream of water, preferably drawn from the jacket of the gas engine, is admitted into a hollow trough, and falling through the bars on to the grate, is there evaporated, mixes with the blast of compressed air, and the two pass together into the furnace. The gases are then led from the top of the furnace into the coke scrubber, upon which water from a siphon is con-

tinually playing through a perforated cone or distributor. The door for withdrawing and charging the coke when required is shown at the bottom of the scrubber S. On their way the gases pass a hydraulic joint,

Fig. 102.—Lencauchez Gas Plant—Elevation.

which is intended to prevent the return of any gas to the furnace. They are next delivered sometimes to a distributing chamber, sometimes direct

Fig. 103.—Lencauchez Gas Plant—Plan.

to the gasholder. By an ingenious arrangement the furnace can be shut off for a few minutes, the injection of air and steam suspended, and the engine driven by gas from the holder while the grate is cleaned, an

operation only necessary about once in twenty-four hours. The holder, of course, contains sufficient gas for starting the engine. The production of gas is regulated by a valve attached by a chain to the top of the gas-holder, through which the compressed air passes to the furnace. As soon as the holder is filled, the valve I is automatically raised, and the air is not allowed to enter the furnace until the contents of the holder have been reduced.

The advantages of this Lencauchez gas producer are its economy of heat and its simplicity, no boiler being required. Both the air and water are usually heated before they enter the furnace, and heat is thus utilised. This producer can also be used to generate gas from cheap and poor coal and lignite. MM. Lencauchez do not find it necessary to burn costly English anthracite in the producer, but inferior bituminous, non-caking French coal, which is much cheaper; a caking coal is found to clog the generator. The system is especially adapted for use where best coal is difficult to procure. French anthracite has neither the same calorific value, nor is it as pure as English. Gas made on the Lencauchez system with English anthracite has a heating value of about 174 B.T.U. per cubic feet at ordinary temperature and pressure; when cheap French anthracite coal is used, its heating value is 152 B.T.U. per cubic foot. With large motors driven by Lencauchez gas, the consumption of fuel is about 1·3 lbs. of good anthracite per B.H.P. per hour. Several large power plants worked with this gas have been erected by the French Compagnie Otto, especially one at Lyons, developing 1,050 H.P. It consists of three two-cylinder engines, each of 300 H.P., all working on to the same crank shaft, and one engine of 150 H.P. There is also a Lencauchez generator driving a 160 H.P. engine at Birmingham, and applications of the system in France are very numerous. The table of trials with power gas at the end of the book gives several tests with these plants. The heat efficiency of the generator is from 75 per cent. to 80 per cent. of the total heat in the fuel.

Various papers have been published by M. Lencauchez, senior, during the last fifteen years, in the *Proceedings of the Société des Ingénieurs Civils*, Paris, and other scientific periodicals, and he has made a careful study of the subject. Both gentlemen, father and son, have been constantly working to improve their generators.

Taylor (Fichet and Heurtey).—The special feature of this generator, made by MM. Fichet and Heurtey, and now by M. Taylor et Cie. in France, and known as "Gaz Mixte," is that most of the heat of the gases is refunded to the furnace, instead of being wasted by cooling them in the scrubber. The process is called "Gaz Mixte" because producer and water gas are made simultaneously, by injecting air

charged with steam into the centre of the glowing combustible. The characteristic features of the generator are (1) Utilisation of some of the waste heat of the gases to superheat the steam and air; (2) Large quantity of steam admitted; and (3) High pressure of the hot air sent on to the furnace. The air, thoroughly saturated by the large amount of steam, is further heated by passing it through a regenerator, in the contrary direction to the gases from the furnace. Thus charged with vapour it enters the generator from below, and passing up through the clinker moistens it and prevents it from adhering to the sides. The steam being superheated before it reaches the injector, draws in with it a considerable amount of air, giving a high pressure. Although, owing to the large quantity of steam with which the air is charged, common and poor cheap coal can be burnt instead of anthracite, the gas produced has a relatively high calorific value, varying from 168 to 196 B.T.U. per cubic foot. A separate boiler is, however, necessary. There is no grate, the coal being charged from a hopper above automatically on to a flat horizontal iron plate, slightly raised in the centre, through which the tube passes conveying the air and steam blast. The bottom of the plate is covered with clinker, and the steam and air percolate freely through it. To clear the furnace a handle outside is turned, the iron plate revolves slowly on its vertical axis, and the clinker is shaken down into the ash box below; the latter is emptied once a week. Thus the furnace is mechanically fed and cleared. When the steam is brought in contact with the glowing fuel, it is immediately decomposed and converted into water gas, and enriches the gas formed from the air. Fig. 104 gives a sectional view of the plant.

A number of these "mixed" gas producers are in use in France and elsewhere. There is an interesting plant near Marseilles, working a 22 H.P. Niel engine, a trial of which will be found in Table No. 5; the consumption was 1·7 lbs. of coke per B.H.P. hour. The Taylor system has also been applied at Orleans, where electricity for driving the tramways is provided by two twin-cylinder Crossley engines, each indicating 165 H.P. and running at 180 revolutions per minute. They are driven by Taylor "Gaz Pauvre" and the consumption is 1·3 lbs. anthracite per B.H.P. hour; the producer gas is used to fire the small boiler. In an earlier trial of a Schleicher-Schumm Otto engine worked with Taylor gas (made by Winand in America) the consumption of anthracite was the same. It has also been used to drive a 56 H.P. Niel engine.

MM. Taylor are of opinion that lighting gas is too costly to be used in France with advantage to drive gas engines, except for very small powers, and they have brought out an engine of their own make, specially designed to work with a suction gas producer they have lately

Fig. 104.—Section of Taylor Power Gas Plant.

introduced. The engine is of the ordinary four-cycle type, strongly built, and has a centrifugal governor. The producer consists of a cylindrical generator, a small cylindrical vaporiser, and the coke scrubber and gas-expansion box. The furnace or combustion chamber is lined with firebrick, the fuel is fed in through a hopper, and, as it burns, sinks down upon the base plate. There are two doors for withdrawing the ashes and lighting the fire, which is started by a hand fan, and cleared, while at work, by inserting a small poker from below. The vaporiser is filled with water, and the gases from the producer are drawn through it by the suction of the motor piston. The same process serves to cool the gases and produce steam, which is led off to the bottom of the furnace, air being drawn in with it. The two pass upwards through the generator, are decomposed by the heat of combustion, and the chemical reactions necessary to form producer gas are obtained. The gas is then drawn through the vaporiser, cleansed and further cooled in its passage through the scrubbers, and finally sucked, by the action of the piston, through the expansion box, which acts as a reservoir, to the motor cylinder. The horizontal engine and producer are made in sizes from 6 to 160 B.H.P., with a speed of 230 to 160 revolutions per minute. More than 12,000 H.P. have been supplied. The 100 H.P. Electric Station at Étampes consists of two electric plants, and two Taylor engines and suction producers, each developing about 54 B.H.P. The suction stroke of the engine is said to ensure the uniform composition of the gas, and the expansion box to regulate the pressure.

Pierson.—MM. Pierson, who are the makers of the Crossley-Otto engine in France, have also brought out one of the most successful of modern gas producers. The essential characteristic of their generator is said to be that the gas is thoroughly purified. The makers consider it undesirable, on the score of economy, to restrict the number of purifiers, and admit a gas which is not perfectly cleansed into an engine cylinder. The same care should be exercised in this respect with producer as with lighting gas, since the same products and inert gases are generated in both cases, though not in the same proportions; and the generator should form an essential part of all large gas engines. Like other producers, the Pierson yields a mixed gas, in which steam and air, acting on the coal, combine to form H and CO. The gasholder is large, and the gas of fairly constant quality and heating value. It is contended that, the greater the care bestowed on these points, the better will an engine work when driven with power gas. A perfectly purified gas cannot, however, be obtained without several purifiers, and the Pierson producer is perhaps somewhat complicated.

It consists of a small high-pressure boiler and an air compressor, from which a regulated quantity of air and steam are sent on to the generator.

The mixture is previously superheated by the waste heat from the furnace, and the heat thus added counteracts that absorbed by the chemical decomposition of the steam. Cheap anthracite, coke, or poor

Fig. 105.—Pierson Gas Producer.

coal is fed in automatically from a hopper above. On leaving the producer the gases are condensed in a cylindrical cooling tower, where the tar is deposited, and thence led to the washer, a column filled with coke moistened with water, where the ammonia and dust are retained.

Lastly, they pass to the purifiers, and are said to be completely freed from the CO_2 and sulphuretted hydrogen before they reach the gasholder. All the parts of the generator are large, and ample space is afforded in all the passages and connections, while the process of gas-making is purposely retarded, to allow time for the different chemical reactions.

The quality and pressure of the gas are sometimes tested at intervals during its production. At M. Danel's Printing Works in the North of France, where two 16 H.P. and 28 H.P. Crossley engines have been working with a Pierson generator since 1898, careful calorimetric tests were made every half-hour with a Junkers calorimeter, to determine the heating value of the gas, and remarkably consistent results were obtained. Taken at five intervals of 30 minutes each, at 0° C. and 76 cm. pressure, the heating value was found to be 1,325, 1,306, 1,301, 1,316, and 1,303 calories per cubic metre, equal respectively to 148·4, 146·2, 145·7, 147·3, 145·9 B.T.U. per cubic foot, or a mean of 146·7 B.T.U. Few generators give such uniform heating value per hour. From 1 kilo. of poor non-bituminous coal 4 cubic metres of this gas can be made, equal to 64 cubic feet per lb. The quantity required is about four and a half times that of lighting gas, and an engine driven with Pierson gas gives from 75 to 90 per cent. of the power.

This producer (see Fig. 105) is especially designed to work with very small coke, or poor hard French coal of any kind, even such as cannot in many cases be otherwise utilised. It is even claimed for it that these inferior fuels are more suitable than anthracite. One of the most important Pierson plants is at the Tunis Gas Works, where three generators have, since May, 1901, supplied power gas to drive four Crossley engines, each developing 195 H.P. The producers are fed with coke from the gas works on the spot, and provide electricity to light the town. The steam and air are led through a superheater on their way to the generator. Another plant at Cassel, near Dunkirk, was tested by Professor Witz in 1900. There are two generators feeding three 26 H.P. Crossley engines, which provide electricity to drive the town tramways. As only rain water is available, steam engines could not be used. The water for cooling the cylinders is continuously circulated, and that required for the small boiler is reduced to a minimum. During the test the heating value of the gas was 139 B.T.U. per cubic foot, and the consumption of poor small French coal 1·4 lbs. per B.H.P. hour. Other plants are at Cannes, where a Pierson generator drives a 100 H.P. Crossley engine, and at the well-known Motor-Car Works of De Dion & Bouton. Here there are ten Crossley engines, driven by two Pierson producers, which have been working, often night and day, since 1897.

MM. Pierson have also brought out a well-designed suction gas plant. The difficulties with this kind of producer, of utilising poor coal, and

of generating with regularity gas of a uniform composition, seem to have been overcome. The plant consists of a small circular water chamber or boiler, surrounding the bottom of the furnace, which is lined with firebrick, and rests on a base-plate, open at the bottom for the removal of the cinders and ashes. Sufficient fuel for ten or twelve hours' work is charged into the generator from above, through a hole in the cover, or a hopper. The steam generated by the heat of the furnace is drawn by the suction of the piston, together with a given quantity of air, through the glowing combustible to the condenser, a wide tube, surrounded by a double water jacket. Here the gases are cooled, the tar condensed, and the dust withdrawn at the bottom. The gas is finally cleansed in a coke scrubber and a dry purifier, and then passed to the engine. Combustion is started by a small hand fan. Variations in the composition of the gas, to suit the work required, are obtained by an ingenious device. If the quantities of steam and air entering the generator

Scale—1 mm. = 1 kilogr. = 14·22 lbs. per square inch.

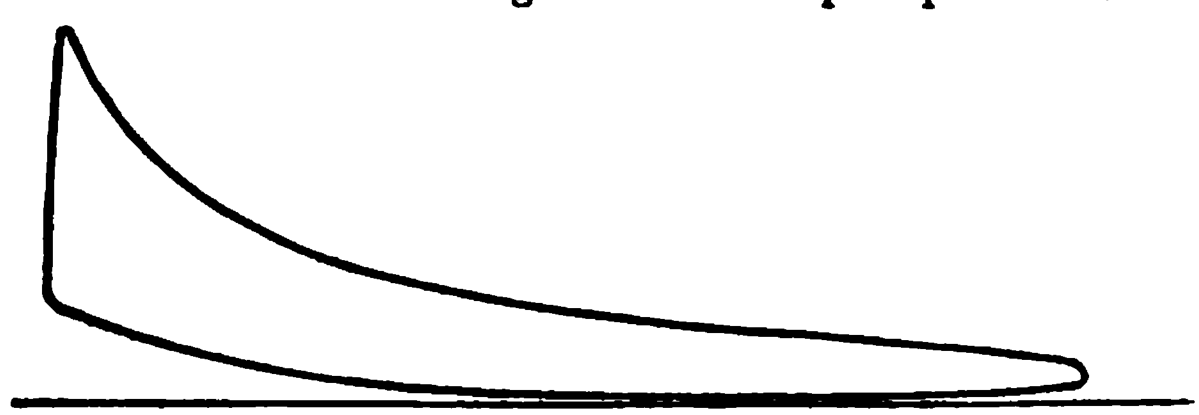


Fig. 106.—Indicator Diagram of 29 H.P. Engine worked with Pierson Suction Producer.

were always the same, the fire would be almost extinguished when the engine is running light, and the suction small, while the temperature of the furnace would be greatly increased when the engine is working at maximum load. The amount of air entering is always the same. The quantity of steam is made to vary with the work, by means of a small air vessel with two valves fixed on the condenser. One of these communicates with the main gas supply pipe; the other is closed by a flexible membrane, and connected through a lever and rod with the steam valve. Communication with the outer air is maintained through a cock at the top. If much gas is required a vacuum is produced in the air vessel, the membrane is sucked against it, the lever and rod are drawn up, and the steam valve fully opened. If little gas is needed, the vacuum is reduced, the membrane scarcely lifted, and the steam valve only slightly opened, or not at all. The fires are cleaned, while the generator is at work, by means of a vertical mechanical poker, moved by a lever from below. The amount of suction required to draw air and steam through

the producer has been shown by diagrams indicating the vacuum to be no more than $\frac{1}{10}$ inch.

In the smaller sizes of this suction producer there is no separate condenser. The tar and dust are eliminated, and the gases condensed, by leading them through a pipe passing down the centre of the scrubber, and cooled by water sprayed from above. The dust collects at the bottom, and is washed out with the water. The producer is made for powers from 8 to 15 H.P. without, and up to 100 H.P. with a condenser. Fig. 106 shows an indicator diagram of a 29 H.P. engine, fed with gas from a Pierson suction producer. A careful trial was made in May, 1904, on a Pierson generator working a 35 H.P. Crossley engine, and fired with small broken coke. From this poor fuel, containing 15 per cent. ash, gas of 127·6 B.T.U. per cubic foot heating value was obtained.

Letombe.—A gas producer of simple design has been brought out by M. Letombe (Compagnie des Fives-Lille). It consists of a cylindrical fire chamber, into which the fuel is charged from the top through a hopper. Air is sent to the bottom of the furnace by a fan, and a suitable quantity of water being previously injected into it, is converted into a fine mist or spray by the force of the blast. Originally the air and water vapour were first led through a spiral coil round the combustion chamber, but this is no longer considered necessary. The mere pulverisation of the water by the air current, the quantities of both being carefully regulated, is said to be sufficient to furnish the steam necessary for the proper working of the generator. The gas produced is led off at the top of the furnace, and cooled and cleansed by passing it successively through a hydraulic box, and coke and sawdust scrubbers, in the usual way. The generator can only be fired with anthracite or coke; the consumption is about 1 lb. anthracite per B.H.P. hour. M. Letombe has also introduced a suction gas producer of the ordinary kind. To this a so-called "compensator" is added, consisting of a small gasholder to equalise the pressure, and cause the producer to work at atmospheric pressure, instead of below it, as in most suction gas plants. (See Table No. 6.)

German Gas Producers.—The **Deutz** firm have devoted special attention to gas producers, being among the first to recognise their great importance. That this is now fully realised in Germany is shown by the fact that more than 500 electric works are driven by power or producer gas; of gas made on the Dowson system the Deutz firm alone have supplied 245 plants, giving 20,000 H.P. To obviate the necessity of burning anthracite or coke, they have brought out a low-pressure producer, in which bituminous coal is converted into clean gas, suitable for driving engines. The apparatus consists of a generator in two parts, an outer annular chamber filled with water surrounding the inner combustion chamber, a coke scrubber, exhaustor or fan, and gasholder.

The top of the generator is open, and air is admitted both above and below. The water in the circular chamber is converted into steam by radiation from the furnace and the heat of the gases, and the steam thus formed is led off through a pipe to the bottom of the generator. Coal is fed into the upper part, where the process of distillation commences, and the gases of combustion pass downwards through the glowing fuel, till they meet the water gas produced at the bottom of the generator by the mixture of steam and air drawn in from below. Here the tar is decomposed, the coal converted into coke, and the gas drawn off is quite clean. The fan draws air from above into the fresh fuel, from below, together with steam, into the column of incandescent coal, and also into the annular vapour chamber. From thence the gas is sent into the scrubber, and through a washer to the holder, the supply being automatically regulated by the action of the fan.

Fig. 107.—Deutz Suction Gas Producer.

Several large plants in Germany are already at work with this producer, one of which is supplying a 400 H.P. engine. It has also been successfully used for making gas from dry peat, of 7,200 B.T.U. per lb. heating value, and containing 17 per cent. water. In a trial made by Professor Meyer, the mean heating value of the gas was 108·5 B.T.U. per cubic foot. A generator for making gas from brown coal has also been brought out, which differs from the Dowson apparatus only by the addition of a dust catcher placed behind the producer. According to the percentage of moisture in the coal, steam is either blown in, or the steam

jet suppressed, and air alone admitted. Brown coal contains more tar than anthracite, and therefore more thorough cleaning of the gas is required. It was with this coal that Professor Meyer's trial was made.

In the Deutz suction gas producer, shown at Fig. 107, the exhaustor is dispensed with, and the vapour chamber surrounds the top of the closed generator. The suction of the piston causes a vacuum, and induces a current of air from the open end of the vapour chamber, which, after passing over the hot surface of the water and becoming charged with steam, is led to the bottom of the generator. The level of water is maintained uniform, and any excess is carried off to the lower part of the furnace. As the gas is automatically produced, the relative proportions of steam and air do not vary. By filling the charging hopper, the generator and engine will work without attention for hours, but only anthracite or coke can be used. The consumption is from 1½ lbs. to 0·9 lb. coke, and 1·2 lbs. to 0·7 lb. anthracite per B.H.P. hour. More than 1,500 of these suction producers, with an aggregate of 50,000 H.P., have been made since July, 1901. They have been applied to marine purposes, and a small river vessel, of 280 tons burden, has been successfully driven by a 20 H.P. engine and suction producer. A 60 H.P. engine worked with a pressure gas producer fired with brown coal containing 50 per cent. moisture was shown at the Düsseldorff Exhibition. The producer is made from 6 to 160 B.H.P.

Both pressure and suction gas producers are also made by MM. Koerting, to work with anthracite or coke. The former are on the Dowson system, with a small steam boiler, and the usual generator, coke and sawdust purifiers, and gasholder. In the suction producer there is no boiler or holder. The steam is generated in the condenser, a small vertical vessel at the side of the cast-iron or wrought-iron generator; the fuel is fed into the latter through a hopper from above. The hot gases are led off at the top of the generator, and pass down through the condenser, where they are cooled, and impart their heat to the air drawn in by the suction of the piston, and to the water in the condenser. These, in the shape of steam or water vapour, are led to the bottom of the generator, and are converted into gas in their upward passage through the fuel. From the condenser the gases are passed through a regulating valve to the coke scrubber, and thence to the engine as required. The number of purifiers depends on the kind of fuel used, and MM. Koerting, like other makers, lay stress on a complete purification of the gas. Suction gas producers are made from 4 to 400 H.P. In the smaller sizes combustion is started by a hand fan, larger producers require from ½ to 3 H.P. to start them. A plant to work with peat fuel is now being erected in Sweden, and in other pro-

ducers lignite is utilised. The consumption of anthracite is about 0·6 lb. to 1·1 lbs. per B.H.P. hour.

The **Vereinigte Maschinen-Fabrik Augsburg,** and **Maschinen-Bau Gesellschaft Nuremberg** also make gas producers. These are of three kinds—pressure generators of the Dowson type, with boiler and gasholder; suction producers, as already described, in which a mixture of steam and air is drawn through the generator by the suction of the engine, the steam being generated by the heat of the gases of combustion in a small vessel contiguous to the furnace; and a third system, similar to the last, with the addition of a fan, to suck the gases from the generator, and send them on to the engine. They are also making experiments with a small producer plant, to be worked with bituminous coal, in which the tar is said to be burnt in the generator itself. Fig. 108 gives a sectional view of a suction producer.

Fig. 108.—Nuremberg Suction Gas Producer.

The **Maschinen-Fabrik Kappel** have also brought out a suction gas producer of the usual type. It consists of a generator with vaporiser attached, in which the water is converted into steam by the heat of the gases. The suction of the piston draws air and steam through the generator, and the gas thus formed is led off through a scrubber, hydraulic box, a dust separator, and an expansion chamber, where any tar remaining is said to be deposited. Only anthracite or coke can be used; the producer is made from 4 to 120 H.P.

Bechstein.—The suction gas producer made by this firm for anthracite or coke is of the usual type, with generator and adjacent vaporiser, a coke scrubber and gas-collector. The ash pit is surrounded by a water jacket, and the water thus heated flows to the vaporiser, where it is converted into steam, and passed through a separate pipe to the bottom of the generator. Here it is mixed with air drawn into the vacuum produced, and the gases generated are treated as already described. These producers and gas engines are made from 4 to 60 H.P. and run at 250 to 180 revolutions per minute.

Oberürsel (Gnome).—This enterprising firm has produced a suction gas plant of the type already described. The upper part of the generator is surrounded by a water vessel communicating on one side with the open air, on the other with a pipe leading to the bottom of the furnace. The steam here formed is mixed with air, passes downwards, enters the furnace from below, and the two are converted into gas, and led off at the top. Heavy incombustible substances are deposited in the pipe connected to the coke scrubber; the remaining impurities are washed out as the gases ascend. If the temperature of the furnace rises, more steam is generated, and the excess of heat thus counteracted. An overflow pipe carries off the surplus water to the ashpit, where it is evaporated, and helps to enrich the gas. The water from the scrubber is collected at the bottom, and forms a seal to the gas. For powers above 30 H.P. an additional purifier is required. These plants are started by a hand fan in from fifteen to twenty minutes, and anthracite or coke is fed in once in every two or three hours. They are made to work with vertical engines in eight sizes, from 4 to 20 H.P., and with horizontal engines up to 140 H.P. The consumption is from 0·8 lb. to 1·4 lbs. anthracite per B.H.P. hour.

The **Langensiepen** suction gas producer is similar to the Oberürsel, and consists of a generator enclosing an evaporating chamber for the steam, a coke scrubber, and gas collector. Anthracite or coke are used; if the latter fuel be burnt, a sawdust purifier is also required. The plant is made in sizes from 6 to 125 H.P.

Suction gas producers of the ordinary type are also made by the **Schweizerische Maschinen-Fabrik**, Winterthur (see p. 187).

Pintsch.—The firm of J. Pintsch, of Fürstenwalde, Germany, have long made producer and water gas on the intermittent system, and claim to run three engines, developing 600 H.P. on producer gas alone, of 87 B.T.U. per cubic foot (780 calories per cubic metre) heating value. Difficulties were at first found in regulating the pressure with gas of such low calorific power, but these have been overcome by placing a governor in the gas main, formed of a simple cylindrical tank, closed above by an inverted bell. At the dead point after the suction stroke,

when the engines draw less gas, the governor bell rises; when the pressure of gas is greatest in the motor cylinder it falls. Variations in pressure are thus corrected, the ratio of pressure of gas to air being maintained constant. The water gas at these works is used for heating purposes.

Herr Pintsch has now introduced a suction gas producer. One of these plants was applied in 1901, with much success, to drive the electric light plant at Heusy in Belgium, where it was seen at work by Mr. Dugald Clerk. The generator is of the usual type; the fuel is charged in at the top through a sliding hopper, to exclude the air. The producer gases are led through a pipe down the centre of the condenser, a cylindrical vessel filled with water, which their heat converts into steam. From thence they pass through a box, forming a water seal, to the scrubbers and dust purifiers, and from them to the pressure governor and engine. The former is similar to the governor already described, but, instead of a bell, it carries a float which rises or falls in accordance with the pressure in the engine cylinder. The air for the generator is drawn in through a pipe from the outer air, through which the gases can escape if the engine stops working. As the generator is worked at atmospheric pressure, the fire doors are easily opened, and the ashes and clinker removed. The consumption is about 1·1 lbs. coke or 0·96 lb. Belgian anthracite per B.H.P. hour. The plant can also be worked with bituminous coal, if more scrubbers are added. It is made in sizes from 4 to 200 B.H.P., and is said to have already furnished a total of 12,000 B.H.P.

Riché Gas Producer from Wood.—This is an interesting and carefully designed producer, though, as the gas is generated from wood, where the latter is cheap, it can scarcely be applied in England. It is the fruit of much scientific study by M. Riché, and is founded on the principle of what he calls "reversed distillation," which consists in forcing the distilled gases to pass downwards through glowing combustible. A very high temperature is also said to be maintained. Hitherto the chief difficulties in making gas from wood have been the large quantity of bye-products generated, and of lime required to purify it. Both have been overcome in Riché's process of reversed distillation, but at the sacrifice of a certain amount of valuable products.

If wood be heated in a retort, the heat first carbonises the external surface, and only slowly penetrates to the internal layers. The gases contained in the woody structure, and liberated by the action of the heat, are at first very volatile. If, as they pass out, they meet a much higher temperature, produced not only by the heat applied, but by the external layer of glowing wood with which they come in contact, dissociation takes place. Part of the gases are converted into fixed hydrocarbons,

and help to enrich those already formed. Riché, therefore, passes the products of distillation through a column of red-hot coke or charcoal, and obtains a highly calorific gas which, although not luminous, is rich, because, being produced in closed retorts, it contains practically no nitrogen. Its composition will be found in the table, p. 300. It has a heating value of about 340 B.T.U. per cubic foot, and thus occupies an intermediate position between lighting and poor gas, being about 2½ times as rich as the latter; but it cannot be used to give light unless carburetted. As the flame burns at 2,000° C. = 3,632° F., the gas thus made is valuable where wood can be cheaply procured. About 100 cubic metres of gas are produced per 100 kilos. of wood burnt, or 16 cubic feet per lb., and in a gas engine cylinder it yields an average of 1 H.P. per 35 cubic feet, and requires from three to four times its volume of air. There are no tarry or other products, and the charcoal obtained often commands a good sale.

Fig. 109.—Wood Gas Producer—Section (Riché). 1899.

The gas is produced in closed cast-iron retorts, of which there are usually several, worked singly or together, according to the power required. Each retort is made in duplicate, and consists of one vertical brick flue, divided into two smaller parallel flues, in each of which an iron retort is suspended. The two flues communicate through a wide pipe. The gases are distilled in one retort, and decomposed and fixed in the other. The distilling retort is a cylindrical vessel, closed below by a cast-iron plug and joint, and shown to the left in the drawing (Fig. 109). The other called the reducing retort, to the right, is of the same shape above, but terminates below in a conical foot, prolonged into a hydraulic box, forming a water seal. The retorts are heated by a Siemens furnace burning fine dust coal or coke. The drawing gives only one set of retorts, but there are usually three or four, all enclosed in the same brick chamber. Air for combustion is admitted above the furnace, through a hole in the charging door, the size of which the stoker can regulate at will. To make the gas, combustion is first started in the reducing retort, and brought to a

bright cherry red. A small charge of charcoal dust is then fed into the distilling retort, and the wood charged on to it. Distillation then proceeds, and the charcoal produced sinks down, is withdrawn from time to time from the bottom, and used to feed the other retort, which is always filled three-quarters full. The gases pass over through the glowing charcoal into the hydraulic box, and thence direct to the holder. If the wood is too dry, a little water heated by the waste gases from the furnace is dropped into the retort, but usually it is damp enough to form steam, and carry off the tar and CO_2. The principle of reversed distillation is carried out in the reducing retort, and upon the temperature in the latter, and the renewal of the charcoal from time to time, depend the quantity and quality of the gas made.

The system has been much criticised by M. Lencauchez, especially with regard to the temperature in the retorts. If they are externally at 800° or 900° C., this would represent an internal temperature of 1,400° or 1,500° C., and the cast iron would melt. M. Riché maintains that the temperature is not so high, but the cast iron is said to be of special quality. From the author's observations, the retorts do not last long, and this is the chief expense in these producers. M. Riché claims to make gas, not only from wood, but from shavings, as in a mill at Calais, where about 3 tons per day of wood refuse and shavings, sawdust, &c., formerly wasted, are now partly converted into gas, furnishing power to drive the machinery. Peat, tan, bark, cotton and paper waste, &c., may also be utilised.

The gas has been applied to several types of engines, as the Crossley, Charon, Niel, &c., and officially tested. The first producer is still working in Peru, and gives a gas distilled from petroleum, driving engines of 120 H.P. A series of trials was made in 1898 at the Sciérie Française at Calais, on a 55 B.H.P. two-cylinder Charon engine, driven with Riché gas. A single retort formed the producer, and generated 1,765 cubic feet per hour of gas, having a heating value of 336 B.T.U. per cubic foot. At the electric works at Ivry (Eure) the Riché producer drives a Charon engine of 35 H.P., and two 10 H.P. Niel engines; the consumption in one of these engines, when tested, was 32·7 cubic feet of gas per H.P. hour. More than 100 small Riché plants have been put down in France and the Colonies. An interesting example is at Majunga in Madagascar, where gas, from an installation comprising a generator with four retorts and two gas engines of 15 and 8 H.P., is used in the manufacture of artificial ice. The gas thus produced from wood is said to cost one-third the price of any other method of obtaining motive power. In another plant at Argenteuil, near Paris, gas made from old railway sleepers feeds a 20 H.P. engine, and is also used for heating.

The Compagnie Riché have lately brought out a producer in which the

gas, instead of being generated in closed retorts, is obtained by direct combustion in the usual way, the principle of reversed combustion being, however, retained. The apparatus consists of a generator with charging hopper above, through which the fuel is fed in. A current of air from a fan driven from the engine is forced into the upper part of the producer, where it comes in contact with the freshly-charged wood, and carries the gases of combustion with it into the lower zone of glowing combustible. Here the gases are distilled and partly burnt, and are forced by the air current through the stepped grate into a wide flue, forming the connection with the scrubber. Into this flue a second blast of air is sent, and the distilled products are again brought to a state of combustion. The high temperature obtained by thus partially burning them produces dissociation, and the great heat maintained in the scrubber, which is filled with coke or charcoal, completes the decomposition of the distilled gases from the generator. From the scrubber they pass to the washer, and thence to the holder and engine. The ashes are removed by a spoon-shaped mechanical poker; in some of the later plants the grate is inclined. No water is used in this producer, the wood being usually damp enough to furnish the necessary moisture, but if the generator is fired with anthracite or coke a little water is admitted at the bottom of the grate, and enriches the gas by the formation of water gas. Any kind of wood refuse, shavings, sawdust, &c., may be successfully burnt in this apparatus. The plant is a good deal used in France, and has within the last few years supplied nearly 3,000 H.P. in forty-two plants, including one in Canada, and others in Roumania, Algiers, and China.

Heat Efficiency.—In a valuable paper on the "Efficiency of Gas Producers" by Mr. Jenkin,* the writer is of opinion that a gas of high calorific value is of more importance than a high efficiency of the producer. To determine the latter the gas must be analysed and the percentage of carbon in the coal and in the ashes, heating value of the coal, and temperature of the gases known. Samples should be frequently taken at different periods after stoking, and drawn off for a longer or shorter time. The gas must be separately analysed for CO_2, CO, H, O, CH_4, and olefiant gas, C_2H_4. The Hempel process is usually employed, and the gas passed into successive pipettes containing the various absorbing reagents. The heating value may be determined either by burning a sample in a calorimeter, or by analysing the gas, and calculating the heating value of each of its chemical constituents. Both methods should when possible be used to check each other; the calorimetric is perhaps the more accurate. As the variations of temperature in the producer greatly affect the quality of the gas made, they should be minimised as much as possible, and should always be noted.

* *Proceedings Inst. Civil Engineers*, vol. cxxiii., p. 347.

In calculating the efficiency of a producer, Mr. Jenkin classifies it under cold gas efficiency—that is, deducting the sensible heat of the gas—and hot gas efficiency, including the sensible heat. As a rule, the heat of combustion of the gas is divided by the heat of combustion of the coal from which it is made. To this Mr. Jenkin adds the proportion of carbon in the coal and that in the gas, estimated by difference from the carbon in the ash. The heat of combustion of the gas is known by volumetric analysis of its chemical constituents. The "Figure of Merit" is a factor obtained by dividing this calorific value by the weight of carbon contained in a unit volume, the product being the heat of combustion of the gas in question, per unit weight. Examples of this method of calculating the efficiency of various gas producers, which he considers as important as the calorific value itself, will be found in the appendix to Mr. Jenkin's paper. The proportion of carbon in the gas shows the efficiency of the grate, and of the method of combustion for a given fuel.

The difference between the hot gas and the cold gas efficiency is the sensible heat per unit volume of the gas. This is equal to the temperature of the gas minus the temperature of the atmosphere, multiplied by the specific heat by volume of each of the gases of which it is composed. The temperature of the atmosphere may usually be neglected in a gas having a temperature varying from 700° to 900° C. The higher its calorific value the lower the ratio of the sensible heat to the heat of combustion of the coal, and consequently the smaller the difference between the hot gas and the cold gas efficiency. Athough the proportion of steam in a gas should be as low as possible, there will always be a certain amount which affects its efficiency. If steam is supplied by a jet, as in the Dowson producer, the heat required for this steam may be taken into account, although it has little influence on the efficiency. An important point is the working of the producer. This depends on the method of introducing the air; to give the best results it should be admitted centrally, the thickness of the fuel should be between 3 and 4 feet, and the consumption about 3 cwts. per hour for a producer having a volume of 40 cubic feet. The quantity of steam admitted may be greatly varied without affecting the efficiency, but the pressure of the blast should be from $1\frac{5}{8}$ inches to $1\frac{3}{8}$ inches of water.

Professor Meyer was among the first to propose to raise the temperature of the air entering a generator by bringing it in contact with the hot products, before they go to waste into the atmosphere. In nearly all the modern gas generators described in this chapter the heat of the producer gases and of the furnace are utilised, sometimes to heat the incoming air, more often to generate steam, and occasionally for both purposes.

The following data of a test on a 40 B.H.P. gas plant (from Mr. Dowson's paper "Gas Power," 1899) may be useful to students:—

One lb. of anthracite gasified in generator, and 0·14 lb. of coke in boiler yielded 78·3 cubic feet of gas (at 32° F. and 29·9 inches pressure), having a calorific value of 175 B.T.U. per cubic foot. The heat balance was as follows:—

	B.T.U.		B.T.U.
1 lb. anthracite, ...	14,760	78·3 cubic feet of gas at 175 B.T.U. per cubic foot, .	13,700
0·14 lb. coke at 12,960 B.T.U. per lb., ...	1,810	Heat lost in process, . .	2,870
Total heat in fuel, . .	16,570		16,570

$$\text{Efficiency of gas plant} = \frac{13,700}{16,570} = \cdot 827 = 82\cdot 7 \text{ per cent.}$$

This is a very high efficiency and probably not very often realised.

CHAPTER XII.

UTILISATION OF BLAST-FURNACE AND COKE-OVEN GASES FOR POWER.

CONTENTS.—Blast-furnace Gases—Chemical Composition—Consumption of Furnace Gases — Utilisation — Economy — Difficulties — Heating Value — Compression— Fluctuations in Composition—Dust -"Static" and "Dynamic" Methods of Purifying the Gas—Thwaite—Theisen—Centrifugal Fans—Gas Engines and Air Blowers — Large Power Engines — History — Experiments — Applications in Different Countries—Conclusions—Summary—Gas from Coke Ovens—Brown Coal Gas—German Power Plants.

INTERNAL combustion engines have now reached a point in their development in which waste gases, and gases other than those generated from coal and oil, are utilised to drive them. This branch of the subject is, perhaps, still in the experimental stage, though much knowledge has now been accumulated, but it bids fair to become of such importance that a brief account of the rapid progress made within the last eight or ten years is necessary. In most countries internal combustion engines are no longer on their trial, but have been sufficiently developed to inspire engineers, mill owners, and commercial men with confidence, and to be applied in very many directions. Within the last few years successful attempts have been made to derive motive force from them by means of various gases now known to be at our disposal. Power is often required in countries where there is no coal, and oil is dear and not available. In such cases, acetylene gas, made from wood, alcohol, peat, &c., may be used.

Blast-furnace Gases.—Of far greater importance than any of these are gases hitherto wasted, which can, when scientifically treated, be turned to account, and made to yield exceedingly valuable results. The utilisation of gases from blast furnaces to drive gas engines in large pig-iron works, although first attempted in an experimental way only about ten years ago, is one of the most important recent developments of engineering skill. It has been proved practically beyond a doubt that internal combustion engines, when placed near these large pig-iron furnaces, can be fed directly with the gases from them, and power may be thus obtained and heat utilised from what was formerly regarded as a waste product. Till within the last few years the usual custom in blast furnaces has been to utilise about half the gases produced, by burning them under steam boilers to generate steam for driving the blowers and to heat the air blast, and to allow the remainder to go to waste. As they were considered of no value, little care was taken to burn the gases economically. The startling and practical discovery has now been made that the blast furnace, besides its primary object of producing pig iron,

forms an ideal gas generator, and the same process is carried out in it as in a generator yielding cheap or power gas. As is so often the case, the idea of turning these gases to account occurred almost simultaneously to inventors in different countries. Their application to produce power in an engine cylinder was made concurrently with the latest developments in gas producers, but we have much yet to learn in this respect.

Chemical Composition.—The products of combustion in these furnaces contain from 24 per cent. to 34 per cent. of combustible gases. As a rule, the latter form one part, chiefly CO, with a small proportion of hydrogen and marsh gas, to two parts of inert nitrogen and CO_2. The average composition, as given by Professor Meyer, is about 12 per cent. CO_2, 25 to 30 per cent. CO, a small percentage of marsh gas and H (about 3 per cent. of the latter), and 55 per cent. to 60 per cent. N. The complex process of generation of the gases seems to be somewhat as follows:—The oxygen in the air blown, and the ore fed, into the furnace converts the carbon in the fuel into carbon monoxide and carbon dioxide. As the gases ascend through the cooler strata of combustible and fresh ore at the top of the furnace, more CO and less CO_2 is generated. Thus their chief constituents are CO and nitrogen. The small quantity of CH_4 is obtained by dry distillation from the coal, and the hydrogen from the moisture in the air and the coke. The CO_2 is due to imperfections in the process of gasification. More of this gas, however, is produced than in generator gas, because some of the CO goes to reduce the iron ore, and burns with the oxygen in it to CO_2, and the latter gas is also present in the fluxes, and driven out by the heat of the furnace.* CO burns with a transparent blue flame, and is not suitable for steam raising, because it contains little heat. Therefore, when burnt under a boiler, blast-furnace gases give an average of only 400 H.P. per ton of pig iron. But if exploded in the cylinders of gas engines of modern type, with the proper proportion of air, they yield about five times as much power. In other words, the same quantity of gas will give 1 H.P. when used to heat a steam boiler for a fairly good steam engine, and 5 H.P. when fired direct in a gas engine cylinder.

Consumption of Furnace Gases.—The economy to be obtained by the application of this new motive power has already been placed beyond question. German and other authorities, professors, engineers, and practical men seem to be agreed upon this point, though in England progress is less rapid. Professor Meyer, one of the pioneers in this important industrial development, thus roughly estimates the saving to be effected. If, he says, the casting of 1 ton of pig iron yields about 158,895 cubic feet of waste gases, having a heating value of 90 to 112 B.T.U. per cubic foot, and if of these as much as 60 per cent. are required to heat the air blast and blowers, the remaining 40 per cent. will, with an estimated

* Meyer, *Ueber Kraftgas- und Gichtgas-Motoren.*

consumption of 4 cubic metres of these gases, equal to 141·2 cubic feet per I.H.P. hour, furnish 20 I.H.P. in a gas engine per ton of iron smelted. This is a higher estimate of the consumption of these gases than is now known to be necessary. Again, taking the fuel burnt as a basis of calculation, if the heat developed yields 1 H.P. for every 2 lbs. of combustible burnt in the furnace, or about double the quantity allowed in power-gas plants, and 1 lb. of this fuel be utilised for driving the blowers and heating the air blast, this will leave ½ H.P. per lb. of fuel, or 1,120 H.P. per ton of iron available for power. The production of the furnace gases has been estimated at from 160,000 to 200,000 cubic feet per ton of iron smelted. The larger the yield the poorer the quality of the gas, because it contains more nitrogen. Making a wide allowance for waste of heat, this would give, say, 1 lb. of fuel per electrical H.P., if the power be applied to drive a dynamo. At the iron works of the Société Cockerill, at Seraing in Belgium, 600 tons of iron are smelted daily. Till within the last few years 40 per cent. of the waste furnace gases have been burnt under boilers to generate steam, producing 2,300 H.P.—that is, only enough power to drive the blowers, pumps, and furnace hoists. With this method of furnishing power, 22 cubic metres of gas are required to produce 1 H.P., and 18 cubic metres are practically wasted, or in round numbers about 10,000 H.P. Each ton of pig iron made yields from 150,000 to 180,000 cubic feet of gas. Taking about 140 cubic feet, or 4 cubic metres, as the consumption per H.P. hour, in a gas-engine cylinder this would give about 1,300 H.P. per hour per ton of iron. The aggregate from all the furnaces at Seraing is therefore from 12,000 to 14,000 H.P. If of this from one-fifth to one-sixth (2,000 to 2,500 H.P.) are required to drive the blowing engines, pumps, &c., the remainder is available for other purposes. To a large extent the gases are now thus utilised at Seraing. It should be noted, however, that the quantity of blast-furnace gases available in any works is so large that economy of consumption is not so important as steadiness in running and good working.

Utilisation.—The following calculations, taken from an article in *Stahl und Eisen*, April 23, 1899, by Herr Lürmann, one of the best authorities on the subject, refer to pig-iron works in Germany, but they can easily be applied by English masters to their own output.

The two main questions in regard to the use of blast-furnace gases in internal combustion engines are, according to Herr Lürmann :—

1. How much power can be generated with gases not required for the production of iron?
2. How much money can be made out of the power thus available?

In Professor Meyer's experiments at Differdingen, in Luxemburg, on a 60 H.P. engine driven with blast-furnace gases, an early, but one of the

most complete tests made, the consumption at full power was 2·28 cubic metres = 80·5 cubic feet per I.H.P. hour of gases having a heating value of 948 calories per cubic metre = 106 B.T.U. per cubic foot. It is better, however, to take the average consumption at 123·5 cubic feet per I.H.P. hour. Reckoning to each ton of pig iron 163,590 cubic feet of furnace gas, having a mean heating value of, say, 101 B.T.U. per cubic foot, of these 45,903 cubic feet, or 28 per cent., are required to heat the air for the blast. In practice the consumption is higher, because there has hitherto been no necessity for economy. If 10 per cent., or 16,348 cubic feet, be taken for loss in pipes, &c., we get as available for power 2,870 cubic metres = 101,340 cubic feet, or 62 per cent., per ton of iron treated. Now, these surplus gases may be utilised in three different ways:—I., The bulk may be burnt under boilers; or II., part may be burnt under boilers and the rest used in gas engines; or III., all the gases may be used in engine cylinders. In the latter case, the air blast for the furnace may be driven by a gas engine. The following table summarises the methods of treatment under these three heads:—

UTILISATION OF BLAST-FURNACE GASES PER TON OF IRON SMELTED.

	I.		
	Cubic Metres.	Cubic Feet.	Per Cent.
Waste in furnace and pipes,	463	16,348	10·00
Heating the air blast,	1,300	45,903	28·06
Driving the blowing engines,	1,820	64,264	39·28
Balance available for other purposes,	1,050	37,075	22·66
(For boilers.)		Total,	100·00
	II.		
Waste in furnace and pipes,	463	16,348	10·00
Heating the air blast,	1,300	45,903	28·06
Driving the blowing engines,	1,820	64,264	39·28
Balance available for other purposes,	1,050	37,075	22·66
(For boilers and gas engines.)		Total,	100·00
	III.		
Waste in furnace and pipes,	463	16,348	10·00
Heating the air blast,	1,300	45 903	28·06
Driving the blowing engines,	504	17,796	10·87
Balance available for other purposes,	2,366	83,543	51·07
(Gas engines only.)		Total,	100·00

In 1898, 7,403,717 tons of pig iron were produced in Germany, or 20,280 tons per day. The available gases might be converted into—

Under Head	I.,	70,000	H.P. per day, or	3·46	H.P. per ton of pig iron.
,,	II.,	253,500	,,	12·50	,, ,,
,,	III.,	570,000	,,	28·16	,, ,,

Thus the difference between the present method and the utilisation of all the gases in gas engines would, after providing necessary power for the furnaces, amount to 24·7 H.P. per ton of iron, or, in round numbers, 50,000 H.P. per day. Assuming that the blowers are driven by gas engines, Herr Lürmann calculates a theoretical saving of nearly 6s. per ton of iron smelted. If only 50 per cent. of this saving were realised, or 3s. per ton, it would, taking the price of coal in Germany at 10s. per ton, amount in the year to over one million sterling. If it is possible, as these figures seem to prove, to effect an economy of 3s. per ton of pig iron, this new method of obtaining power is worthy of the serious attention of all iron-masters. Probably about two million H.P. might thus be utilised annually in England alone, instead of being wasted. By burning their surplus gases in engine cylinders, blast furnaces could be converted at little cost into central power stations, and a fresh industrial stimulus might be given to a whole district. Much would depend on whether the iron works could themselves make use of all the surplus power, or sell most of it. The power available may be tabulated as follows (see *Engineering Magazine*, June, 1898):—

For furnaces making	300	tons of pig iron per week, . .	2,019 H.P.
,,	400	,, ,, . .	2,692 ,,
,,	600	,, ,, . .	4,038 ,,
,,	700	,, ,, . .	4,711 ,,

Difficulties.—We come next to consider the question of the difficulties to be overcome before this vast store of surplus energy can be utilised. The chief objections which have been urged against the use of blast-furnace gases in internal combustion engines are:—

I. Their poor quality and low heating value, causing uncertainty or perhaps failure of ignition in gas motor cylinders.
II. Irregular action of the engine, due to unavoidable fluctuations in the composition and pressure of the gases, caused by firing, &c.
III. The large quantities of grit and dust, chiefly metallic, coming away from the furnace with the gases, which may injure the motor cylinder, and decompose the lubricating oil.
IV. High temperature of the gases.

We will now treat these objections in detail:—

I. **Low Heating Value and Compression.**—As regards the com-

position and heating value of blast-furnace as compared with other gases, the following table gives data obtained from England, Scotland, Belgium, and Germany :—

TABLE OF HEATING VALUE AND COMPOSITION OF VARIOUS GASES.

Name of Gas.	Heating Value B.T.U. per cub. ft.	Analysis in per cent. by Volume.				
		CO.	H.	CH_4.	CO_2.	N.
		per ct.	per ct.	per ct.	per ct.	per ct.
Lighting gas (mean),	600 to 640	6·70	46·40	41·50	2·10	3·00
Generator gas,	130 to 165	26·10	3·60	10·00 (HO)	9·00	51·30
Blast-furnace gases—						
Wishaw,	97·8	24·75	2·33	0·75	5·75	66·42
Frodingham,	96·7	27·30	1·50	...	6·00	65·20
Seraing,	109·8	27·90	1·02	7·00 (HO)	13·95	50·12
Hoerde,	107·5	32·00	2·50	...	8·50	57·00
Gas distilled from brown coal,	225 (mean)	17·50	20·00	1·50	15·00	20·00 (mean)
Coke-oven gas,	540·0	8·20	53·00	34·50	2·00	4·90

The low heating value of the gas, as here shown, does not affect its efficiency in a gas engine. The lower its calorific power, the higher the compression it will bear without danger of spontaneous ignition, or sudden explosive shocks. It is the hydrogen in the gas which, when raised to a high temperature by compression, causes the gaseous charge in the cylinder to explode prematurely. A reference to the table above shows that the average percentage of hydrogen is lower in blast-furnace than in any other kind of gas. Volume for volume, if these gases be compressed to the same extent as others, they will show a much lower heat efficiency, but, if greater compression be adopted, they will give as high, if not a higher, efficiency. As is now well known, the thermal efficiency of an engine increases within certain limits with the degree of compression, and it is towards this higher compression that the efforts of gas engineers are continually tending. The poor quality of any gas does not affect its efficiency if, when burnt in an engine cylinder, it can turn a large percentage of the heat supplied to it into useful work. An engine has been driven (see p. 234) with gas of 87 B.T.U. per cubic foot heating value; that is considerably less than the poorest blast-furnace gases hitherto used. With previous compression of the gases to 10 atmospheres, a heat efficiency of over 30 per cent. per I.H.P. has been obtained with blast-furnace gases, or the same as in the best gas engines.

These gases are difficult to burn because they contain so little hydrogen. For this reason they are suitable for combustion in gas

engines in which the charge is previously compressed, because, however high the compression, pre-ignition, as with lighting gas, is impossible. Combustion is relatively slow, and therefore engines driven with these gases run more quietly than with town gas. If the compression be properly proportioned, ignition is practically certain. On this point Professor Meyer says:—"To obtain good combustion in an engine cylinder, each particle of gas must find and mix with the quantity of air necessary to burn it perfectly. Therefore the streams of gas and air should be well mixed during admission, instead of pumping the gas into the cylinder when it is already full of air, as is sometimes done. The difficulties of premature ignition when driving gas engines with furnace gases have been overcome by high compression during the second stroke. The poorest gas can be thus utilised, and compression carried much higher than is allowable with lighting or power gas. This will diminish the consumption, and it obviates the necessity for larger dimensions of the cylinder, since 1 cubic foot of lighting gas burns with about 7 cubic feet of air, and 1 cubic foot of furnace gas requires only 1 cubic foot of air." It must not be forgotten, however, that if air and blast-furnace gases be mixed in such proportions as to be as rich as a charge of lighting gas by *volume*, they are not of the same value by *weight*, because the air admitted to dilute the charge carries with it a large proportion of nitrogen. As the heating value of blast-furnace is only one-fifth that of lighting gas, the power developed will be from one-fifth to one-fourth less, or about 20 H.P. per cent. According to Professor Meyer, small variations in the heating value do not affect the power developed.

It is owing to this compression, now easily obtained, that gases of such low heating power can be effectually utilised in a gas engine cylinder, but when burnt under boilers they do not give equally satisfactory results. Their calorific value would be higher were it not that the greater the efficiency of the blast furnace, or the more CO_2, and the less CO is produced for a given weight of fuel burnt, the less suitable are the gases for combustion in an engine. To improve combustion in the furnace, metallurgists have rightly endeavoured to reduce the percentage of CO and increase that of CO_2; but for power purposes in an engine cylinder, CO_2 is of no value, and CO is very important. According to Sir Lowthian Bell, the CO_2 should never exceed half the CO formed. "The smaller the consumption of coal or coke in a blast furnace," says Professor Meyer, "and the higher the efficiency of the furnace, the smaller the work obtained from the gases when used to produce power in an engine." Fluctuations in their heating value may be avoided by regulating the admission of the air and gas to the cylinder, so that a richer mixture enters if the heating value of the gas

diminishes. It is, of course, of special importance to determine the calorific power of these gases, as it is the only means of estimating that of the combustible burnt. The exhaust gases from the cylinder should also be analysed.

The large percentage of nitrogen does not, with modern methods of construction, present much difficulty. From three-tenths to one-third by volume of blast-furnace gases are combustible, the remainder being inert, and acting as diluents (see Table, p. 246). The gas in an engine cylinder must, however, always be diluted, and the ratio in which it should be combined with air to form an explosive charge, and give the best results, being known, all that is necessary with blast-furnace gas is to regulate carefully the air admitted for combustion in the same way, though not in the same quantities, as with lighting and power gas. The modifications required are to proportion the gas and air inlets and the stroke of the piston to the charge, and to diminish the compression space. To give the same power in an engine as when driven by lighting gas, the cylinder dimensions must be increased by about 16 to 20 per cent.

II. As regards the fluctuations in the **composition and pressure of the gases**, these are not much more marked than with lighting and power gas. Variations in pressure are avoided or corrected by passing the gases from several furnaces into a holder. They are produced in such quantities that uniformity of composition is more or less assured. To make pig iron, the furnaces must be stoked and charged, and the air blast delivered with great regularity, and the quality of the gases does not then vary much. It is even said that gas engines run more steadily when driven with blast-furnace than with lighting or power gas, because of the far greater size of what may be called the generator. For electric applications this point is of advantage.

III. **Dust.**—The third, which has usually been considered, and still remains the greatest difficulty to overcome in the utilisation of blast-furnace gases for power, is the dust they contain. As many of the objections raised to their use are based upon this question, it is necessary to consider it in detail. It was at first thought that the fine particles of solid carbon, and the metallic dust with which the gases were charged, would be deposited in the pipes and passages, and, even if they did not affect the parts of the engine, might attack the lubricating oil, and make it thick and hard. These drawbacks, however, although serious in some cases, have been successfully overcome, and in the opinion of an eminent German authority blast-furnace gases are now more thoroughly cleaned, and soil the engines and valves less than producer gas. As the furnaces are mostly stoked with coke, the gases contain little tar.

Like other questions connected with the use of these gases for motive power, this problem of the dust they contain was not at first understood.

It is now known that the dust is of two kinds. The heavy dust chiefly consists of small particles of coke, mineral, and lime from the fluxes; this is almost wholly deposited in the mains through which the gases are led off from the furnace. From this dust they have always been purified, even when only burnt under boilers or used for heating purposes. The real difficulty lies in dealing with the light impalpable dust, which is so fine that the earlier methods of treating it were of little use; it was even known to pass with the gases through a layer of felt 4 inches thick. This dust, which consists chiefly of fine mineral and lime powder deposited by the metallic vapours, and sometimes of a kind of dried and powdered clay, usually varies in amount from 3 to 5 grammes per cubic metre. (At the trial at Seraing in 1900, in which the author took part, he collected some of it, and found it soft to the touch, not gritty, but somewhat resembling flour.) The idea was at one time entertained that it could be blown out with the gases of combustion at exhaust, but this is now known not to be the case, and unless the dust is eliminated before the gases reach the engine, it settles on and clogs the valves and working parts. A point to be noted in connection with it is that it varies greatly with the kind of ore smelted. Where the furnaces deal with hæmatite and purple ores, the dust is rather heavy, and is mostly deposited as soon as it leaves the furnace. If oolitic ores are fed in, the dust is much finer, and more is produced. Hence no general rule for cleaning the gases can be laid down. The dust must be separately treated at each iron works, according to the ores and fluxes used, and the fuel fed into the furnace, whether coal or coke.

Two methods, known respectively as the "static" and the "dynamic," or the dry and the wet process, are used for eliminating the dust. The first is the system adopted by Mr. **Thwaite** and others. The gases are drawn by an exhaustor through coke and sawdust scrubbers, in the same way as producer gas. At his plant at Outreux they are led through sieves or metallic layers, the effect of which is said to be increased by charging them with electricity, and are then cooled by passing them through various washers to the scrubbers and sawdust filters. At Michéville, under M. Lencauchez's supervision, and at Gutehoffnungshütte the gases are also treated by the static process. At Friedenshütte, where they contain 30 per cent. of zinc dust, much difficulty was at first found in dealing with them. They are now passed through eight dry purifiers, all with hydraulic joints, and led up and down a total length of 720 feet, besides being carried through several sawdust filters. One square foot of filtering surface is required for every $3\frac{1}{2}$ cubic feet of gas. A Koerting steam injector is sometimes used to draw the gases from the furnace.

The **Theisen** apparatus belongs to the "dynamic" type of purifiers,

and has met with some success in Germany, especially where an abundant supply of water is not available. It consists chiefly of a centrifugal washer, with a long, large pipe in which the dust settles; the washer is driven by a belt from a separate engine. In the original plant, as used

Fig. 110.—Centrifugal Fan for Cleaning Blast-furnace Gases.

at Hörde, the pipe was about 12 feet long and 5 feet in diameter. On entering the purifier the gases contained 3·3 grammes of dust, and 36 grammes of water per cubic metre, and 0·01 gramme of dust, and 3 grammes of water on leaving it. About 2·5 per cent. of the total power generated was required to drive the washer. The plant was at first

somewhat large, and did not work with complete success; it has now been modified, and reduced in size. The quantity of water required is 0·8 litre to 1 litre per cubic metre of gas (= about ·05 pint per cubic foot), and the same water can be used for two weeks if properly cooled and cleared. The temperature of the gas is reduced from 300° F. to 86° F., and its pressure from $\frac{3}{4}$ inch to atmosphere. An apparatus capable of treating 6,000 cubic feet per minute will serve a 50 H.P. engine. The speed of the fan is 100 feet per minute.

In the first attempt to drive gas engines on a large scale at Seraing, no difficulties were experienced with the dust, the quantity of which, owing to the kind of ore treated (hæmatite and purple ore), was only 0·25 gramme per cubic metre. As soon, however, as Cockerill engines were started at Differdingen, in Luxemburg, the dust in the gases, which amounted to from 4 to 5 grammes per cubic metre, was found to have an immediate effect in clogging the cylinder, &c. An ordinary centrifugal fan, till then employed for other purposes, was brought into use, and the gases passed through it, water being injected into the axial part of the fan. The result was completely successful, the gases on leaving the fan being quite clean enough for work in an engine cylinder. This "dynamic" method of treating the dust, which consists in passing the gases through one or more centrifugal fans, with water injections, is now considered the most satisfactory system. The gases are violently agitated by the vanes of the fan, the water pulverised, and the dust washed out by the force of the jet.

Fig. 110* gives a view of the fan as used at Differdingen. The body of the fan is shown at A, at B the water and dust accumulate, and are carried off through pipes *c* and *b*. The gas enters at C, and passes out at D through the outlet valve E. The fan at Differdingen is about $4\frac{1}{2}$ feet in diameter, and runs at 900 revolutions per minute. The gases contain 4 grammes of dust per cubic metre on entering; the quantity on leaving depends on the amount of water sprayed into the fan; with 2,200 gallons of water the dust is reduced to 0·30 gramme, and with 3,300 gallons to 0·20 gramme per cubic metre. If a second fan be used, the gases are still cleaner. Another advantage of this system is that the gases are sent on at a pressure of $\frac{4}{5}$ to 1 inch of water, which suffices to carry them through the narrow pipes to the engine. At the Ormesby Iron Works, where the first large engine driven with blast-furnace gases was started in England, the gas is of 110 B.T.U. per cubic foot heating value, and contains 1·8 grammes of dust per cubic metre after being passed through a large main to reduce its temperature. It is then sent through a 36-inch centrifugal fan, driven by an electric motor, and water is admitted at the axis of the fan. With a speed of the latter of 1,150 revo-

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lutions per minute, and a water consumption of 500 gallons per hour, the dust is reduced to 0·4 gramme per cubic metre, the consumption of water being 1 litre per cubic metre (= say, ·05 pint per cubic foot). The gases are then passed through a coke filter on their way to the engine. The fan requires to be cleaned every fortnight, which necessitates a second fan in reserve.

The question of cleaning the gases may thus be considered as satisfactorily settled, but the degree and method of cleaning required in any particular iron works must be determined by local working conditions.

IV. **The High Temperature of the Gases** is regulated at the same time and in the same way as their purification. They require thorough cooling, as they are generated at a much higher temperature than power gas, but this is efficiently done during the process of washing. To reduce their temperature is an important matter, because they are at the same time reduced in volume, and a larger quantity can be admitted into the cylinder per stroke.

Gas Engines and Air Blowers.—A minor but important question is whether the air-blowing engines for the hot blast can be driven direct from gas engines worked by blast-furnace gases, and thus a great saving be effected over the present rather wasteful system of driving them by steam. Better arrangements for heating the air blast would also contribute to economy. The volume of furnace gases needed to heat the blast is reckoned at 50 per cent.—in other words, 20 per cent. more than is theoretically required (see Table, p. 244). To ensure a better distribution of the hot products of combustion in the air-heating chambers, various modifications have been proposed. The Böcker system, in use at the Friedenshütte Works, is preferred in Germany, and is said to require much less gas. Tests made by Professor Meyer showed that with this method 40 per cent. of gas was economised, thus reducing the consumption nearly to the theoretical minimum of 28 per cent. Improvements in the valves of the blowing engines are in progress. To couple a gas engine with a blowing engine was till lately a novelty, because the speed of the former is usually from 120 to 130 revolutions, and that of a blower only from 30 to 60 revolutions per minute. To remodel the valves of the blower is, perhaps, the best way, and two patents of this kind have been taken out in Germany, the Lang-Hörbiger and the Stumpf-Riedler. Valves of the Lang-Hörbiger type have been applied with good results to blowing engines, especially at Seraing, and they allow of a speed up to 120 revolutions per minute. Either the speed of the blowers must be increased, or that of the gas engine reduced. According to the Deutz firm, the latter method presents no difficulties. At Seraing the piston-rod of the gas engine passes through a stuffing-box on the cylinder head at the back, and is coupled direct to

the piston of the blower, and this is now the system generally adopted. Gas engines thus connected must run at rather low speeds. Professor Meyer found that the speed of an 8 H.P. engine driven with lighting gas could be reduced to half the normal, without increasing the gas consumption or affecting the ignition; the governor and flywheel prevented any further reduction of speed. These experiments seem to show that the working process in a gas engine can be as satisfactorily carried out at 50 revolutions per minute, as at ordinary speeds.

Some writers, however, consider that the speed of a gas engine cannot be greatly varied, and its highest efficiency is attained when running at maximum speed. It is impossible, they say, to force it, and the governor acts only by diminishing, never by increasing it. Thus to utilise blast-furnace gases efficiently it appears desirable in most cases to increase the speed of the blower, and not to diminish much that of the gas engine, in which a reserve of power is always desirable. A higher pressure of air in the blowing cylinder is generally obtained, without varying the load, by diminishing the quantity of air drawn in, and delaying the beginning of compression. With the same object the Nürnberg Maschinen-Bau Gesellschaft enlarge the clearance or expansion space. This firm make a speciality of gas engines directly coupled to blowing engines, and build the latter with an intermediate "guide" piece concentric to the gas engine cylinder. If less air is required for the blast, the speed of the gas engine can be reduced 50 per cent.; but if the quantity of air delivered by the blower varies greatly, the suction inlet can be so adjusted that part of the air drawn in is blown out again. The Cockerill firm adopt a somewhat similar arrangement. The automatic valve on the blowing engines is connected by levers to stepped cams on the side shaft, the action of which is controlled by an air barrel governor. If the normal pressure is exceeded, the air governor delays the closing of the automatic valve. More air is allowed to escape, less remains to be compressed, and thus the pressure is made to regulate automatically the delivery of air to the blower.

Large Power Engines.—The most important question of all, however, for both gas engineers and iron masters is whether the gas engine, which was at first made only for small powers, can be built for the very large powers now necessary to utilise to the full this new and valuable motive force. The need for large engines is evident, not only because of the great quantities of furnace gases generated and their low heating value, but because in smelting and metallurgical works powerful motors are required. The unforeseen discovery that waste gases can be turned to excellent account has given a fresh impetus to the construction of large gas engines. That the necessity for them has been realised, and the demand fully met, may be seen by comparing the sizes of engines now

built by the principal firms with those made ten years ago. It is, perhaps, not too much to say that in this respect the introduction of this new motive power has, since the beginning of this century, created a revolution in the construction of gas engines. This has led to great improvements in gas producers, and to fresh efforts to utilise ordinary or poor coal in them, which is much to be desired. The field for gas engine industry is greatly enlarged, and important firms, who have hitherto made steam engines only, are taking up their manufacture. An account of the number of engines built and powers developed up to present date (1904) will be found at pp. 140, 258, and also in the chapters describing the different types. Mr. Humphrey * estimates that there are now 50 firms manufacturing engines of 200 H.P. and upwards, and the number of large engines for driving dynamos worked with blast-furnace and power gas was 400 in June, 1903, with a total of 206,800 H.P. Nearly 100,000 H.P. are furnished by blast-furnace gases in Germany.

Nevertheless there are difficulties in the way of these large engines, some of which have been discussed in Chapter vii. In the ordinary type of gas engines for medium powers there is only one motor stroke in four, and for high powers the single cylinder and connecting-rod must be made very large, and the walls and working parts require careful cooling. Now, the larger the cylinder diameter the less easy is it to control the temperature of the internal charge by the cooling water jacket. The distribution of heat being unequal, the valves may be affected, but this trouble can be avoided by an elaborate system of cooling. In considering these obstacles Professor Meyer points out the various difficulties which have been already overcome, and how the size of gas engines has steadily increased from very small powers. For blast-furnace work engines are now built larger than for any other type of internal combustion motor. At Seraing the Société Cockerill construct single-cylinder Simplex engines, developing 650 I.H.P. and 550 B.H.P., with a cylinder diameter of 1,300 mm. = 4·2 feet and 1,400 mm. = 4·5 feet stroke, running at 80 to 90 revolutions per minute. The diameter of the blowing engine cylinder is 5½ feet. They have also a 700 B.H.P. engine now running. That so important a firm should adhere to the single-cylinder type for such large powers is a fact worth noting. The builders of the largest size motors are probably the Westinghouse Co.; the largest single-cylinder engine would appear to be a 750 H.P. Nürnberg motor running at the Rheinische Stahlwerk, Meiderich, Germany.

History. — The utilisation of blast-furnace gases in combustion engines has for several years much occupied the attention of engineers

* See Mr. Humphrey's excellent paper on "Recent Progress in Large Gas Engines," which should be consulted by the student desiring the latest details on this subject.

and metallurgical experts. The process was started almost simultaneously in England, Germany, and Belgium, perhaps first in England. In February, 1895, Mr. Thwaite, to whom much credit for early pioneer work is due, drove an Acmé 30 H.P. engine with blast-furnace gases at the Wishaw Iron Works, near Glasgow, and this seems to have been the first time the idea was put in practice. The engine provided electric light for the works, and ran quite satisfactorily; it had a cylinder diameter of 12 inches, with 20 inches stroke. The consumption was 95 cubic feet of gas per B.H.P. hour, but as the furnace was fed with coal instead of coke, as usual, the gases were richer, and therefore the consumption relatively low. In a test made by Mr. Booth on the electrical energy developed by this engine, the consumption varied from 1¼ to 1½ lbs. of coal in the furnace per electrical H.P., according to the amount of fuel burnt and richness of the gas made. Another small experimental plant was worked for some years at Frodingham, near Doncaster. The tests made on this engine, which was also an Acmé, are valuable, because the gas was poor, and they first proved that blast-furnace gases of inferior quality may be utilised in an engine cylinder. A 160 H.P. engine is also working at Barrow-in-Furness, and a Thwaite-Gardner 400 H.P. engine was erected in 1901 at the Clay Cross Iron Works. A Premier engine developing 250 H.P. was constructed by the Premier Gas Engine Co. in 1899 for use with blast-furnace gases, a drawing of which will be found in *The Engineer*, Dec. 15, 1899.

In December, 1895, an 8 H.P. Simplex engine was started experimentally at the Société Cockerill's Works at Seraing in Belgium. The motor was originally 4 H.P., but with higher compression up to 10 atmospheres and other modifications the power developed was soon doubled. The consumption of blast-furnace gases was 5,300 litres = 187 cubic feet per B.H.P. hour, and the results were so satisfactory that an engine of 200 H.P. was soon provided. For this engine the gases are passed through the coke scrubbers, each 4·9 feet in diameter and 19·6 feet high, the water for washing the coke being supplied by Koerting injectors. A careful trial was made in 1898 by Professor Witz, when the engine developed 182 B.H.P., with a previous compression of the gases to 7½ atmospheres. The calorific value of the gas was 981 calories per cubic metre, equal to 109·8 B.T.U. per cubic foot, and the consumption per hour per B.H.P. 3·33 cubic metres, or 117·5 cubic feet. The engine has since been working uninterruptedly at Seraing.

The immediate result of this success was the order of a plant on a hitherto unprecedented scale for the Differdingen Iron Works in Luxemburg, where nine Cockerill engines, with a total of 5,400 H.P., have for some years been installed. Three of them are coupled to dynamos, six drive the blowing engines. No steam engines are in use at Differdingen,

all the power required being furnished by gas engines driven with blast-furnace gases. Fig. 111 gives a view of the installation. A 600 H.P. engine was next built and tested by several scientific experts in March, 1900. It was one of the first coupled direct to a blowing engine. At the end farthest from the crank shaft the piston carries a rod which

Fig. 111.—Gas Engines at Differdingen (Delamare-Deboutteville and Cockerill System).

6 Blowing engines of 600 H.P.	= 3,600
3 Engines for dynamos	= 1,800
Total H.P., ...	5,400

passes through a stuffing-box closing the combustion chamber, and directly connected to the piston of the blowing engine. This motor was erected at the Ormesby Iron Works, Middlesbrough, where, after the initial difficulties inevitable in a new installation had been overcome, it

has since been working with entire satisfaction. Fig. 112 shows a drawing of this interesting engine, the first driven with blast-furnace gases for

Fig. 112.—600 H.P. Cockerill Engine at the Ormesby Iron Works, Middlesbrough.

large powers in England. A drawing of the large central plant at the Seraing Works will be found at p. 139, Fig. 72.

The Hörde Iron Works were the first to adopt blast-furnace gases for power in Germany. An experimental 12 H.P. Otto engine was started there in October, 1895, in which the consumption of blast-furnace gases was 4 cubic metres = 141 cubic feet per B.H.P. hour. It ran so successfully that the authorities added a two-cycle Oechelhaueser engine with two motor cylinders, each 18·9 inches diameter and 31 inches stroke, and each giving 300 H.P. This 600 H.P. engine was seen at work by the author. There are now three 600 H.P. Oechelhaueser engines driving dynamos at Hörde. In the large plant at Ilsede, mentioned at p. 173, the Oechelhaueser engine is coupled direct to the blowing cylinders, and its speed automatically varied in accordance with the different pressures of air required. Thus the work of the engine is practically constant, and a governor is not necessary. The Deutsche Kraftgas Gesellschaft, formerly the Berlin-Anhaltische Gesellschaft, make this two-cycle engine for blast furnace work. The arrangement they adopt is to place the blowing cylinder immediately behind the power cylinder, and the pump below it, like the condenser of a steam engine.

The well-known Gas Motoren Fabrik Deutz have many large plants working, or in course of construction. At Friedenshütte in Upper Silesia there is a 1,000 H.P. installation with four engines, two developing 200 H.P. and two giving 300 H.P. Two of these have been running since January, 1899. A 600 H.P. Otto cycle engine with four cylinders and two cranks has been running night and day since August, 1900, at Dudelingen in Luxemburg, where there are now four engines developing a total of 3,200 H.P. These engines work with so high a degree of uniformity that they are used to drive dynamos in parallel. There are also four Deutz engines at Hörde giving 4,250 H.P., and at these works a 2,000 H.P., the largest Deutz engine yet built, is shortly to be erected. A Deutz engine supplied to the Michéville Iron Works by the Compagnie Française des Moteurs à Gaz, was the first in France worked with blast-furnace gases. Up to February, 1904, this noted firm had built 51 engines for this kind of work, with a total of over 28,000 H.P.

MM. Koerting, the largest gas engine builders next to the Deutz in Germany, have also devoted much attention to the subject, and details of engines erected by them or their licencees will be found at p. 162. Up to the present time they have constructed 50 motors, aggregating 78,000 H.P., for blast-furnace work. They claim to run their engines at a constant speed varying from 25 to 110 revolutions per minute, to suit the varying pressures required in the blowing engines. The Augsburg Maschinen-Fabrik and Nürnberg Maschinen-Bau Gesellschaft also build large gas engines, and have made 31 driven with these gases, aggregating 38,000, H.P. or more than 1,200 H.P. per engine. Other German makers whose engines are described in Chapter ix. are Louis Soest,

Dinglers', the Siegener Maschinen-Bau Gesellschaft, who have built nine, and MM. Borsig, who have constructed nineteen engines driven with

Fig. 113.—Blast-furnace Gases—Crossley 530 H.P. Gas Engine.

blast-furnace gases. Similar motors are also made by Letombe in France. Of English makers, besides those representing foreign firms, there are Messrs. Crossley, the Premier Gas Engine Co., who build 400 H.P. and

1,000 H.P. engines for blast-furnace work, and the Westinghouse Co. Messrs. Crossley have supplied a 500 H.P. engine coupled direct to a blowing engine, drawings and a description of which will be found in *The Engineer*, April 5, 1901. Fig. 113 gives a view of a 530 H.P. Crossley engine. For the Cockerill engines built at Seraing, see p. 140.

Trials.—A series of very careful tests were carried out in 1898 at Differdingen in Luxemburg, by Professor Meyer, on a 60 H.P. Otto four-cycle single-acting engine made by the Berlin-Anhaltische Maschinen-Bau Gesellschaft, and driving dynamos for lighting the works. To burn blast-furnace gases with this engine the compression space is made rather smaller than usual, occupying about one-sixth of the total volume of the cylinder, and the gas and air passages are slightly modified. The power developed was 67 B.H.P. with furnace gases, 80 B.H.P. with lighting gas. At these works the gases were drawn from the furnace by a pump driven from the gas engine, and forced through scrubbers 15 feet high filled with coke moistened with water, and a sawdust column in four stages, to the gasholder, which is 25 feet diameter.

The engine is of the ordinary four-cycle type. The holder was carefully gauged during the experiments, to determine the quantity of gas used. The temperature of the gases was taken between the holder and the cylinder. In an engine governed on the "hit-and-miss" principle, Professer Meyer has found that, immediately after a missed explosion, the composition and weight of the next charge drawn in are not the same as when the engine has been running regularly, being affected by the lower temperature produced in the cylinder by the absence of combustion. These differences are shown by the shape of the explosion curve in the indicator diagram. Thus a diagram taken at normal speed will give a much larger area of work than one taken directly after a missed explosion. In testing the engine at Differdingen, therefore, Professor Meyer took fifteen diagrams, one over the other, and, as the governor gave about one missed explosion in nine, the fifteen diagrams fairly represented the average pressure of explosion. The work on the brake, or mechanical efficiency, calculated from the electric H.P., was about 84 per cent. The gas was tested every ten minutes in a Junkers calorimeter, and its mean heating value determined at 105 B.T.U. per cubic foot. The engine ran very steadily and quietly; for fuller details see Table No. 7.

The mean number of revolutions was 160, mean pressure 4·8 atmospheres, electric H.P. 56·8. The consumption of furnace gases under exceptionally favourable conditions was 2·28 cubic metres, equal to 80·5 cubic feet per I.H.P. hour. The indicated heat efficiency—*i.e.*, the quantity of heat converted into indicated work—was 32·2 per cent., heat lost to the cooling jacket 22·5 per cent. At half load the consumption

of gas per I.H.P. hour increased very slightly, and the heat utilisation was almost as good as at full power.

A trial which has become of historic interest, and to which many scientific men from England, France, Germany, and Austria were invited,* was made at the Seraing Works in March, 1900, on the 600 H.P. Cockerill-Simplex engine shown at Fig. 112. The experiments lasted three days, and were carried out by M. Hubert, a distinguished engineer of Liège. The gas from the furnaces was forced by four Koerting injectors into the cooler, and passed thence to the engine, no cleaning being required. The mean heating value of the gas was about 110 B.T.U. per cubic foot in Professor Witz's bomb calorimeter, and 97·3 B.T.U. in the Junkers calorimeter. The first day's trial was preliminary; on the second day the engine drove itself only, and on the third day it was attached to the blowing engines. The speed on the two latter days varied from 84 to 91 revolutions per minute, and the thermal efficiency per I.H.P. on the second day was 30 per cent. The consumption of gas per B.H.P. hour was 123·7 cubic feet on the second day's trial, and 110 cubic feet during the third day. Full details and dimensions of the engine will be found in Table 7.

Conclusions.—The most important question to be solved is whether large gas engines, at the temperatures and pressures developed in the interior of the cylinders, and their comparatively high piston speed, may be relied on to run safely and steadily for a long period without undue wear. For lighting gas large engines will probably not be often built in the future, except near gas works, to utilise the coke, or where the power required is intermittent. The question, therefore, is one which mainly concerns power and blast-furnace gases. Professor Meyer has visited a number of large gas plants, and found all satisfactory in this respect. The system of driving engines with blast-furnace gases is still in its infancy, but so far no failures have been recorded. Furnace works which began with small powers are now ordering much larger motors.

Whether the Otto cycle with its one motor stroke in four is the most suitable type for this class of work is a moot point. The results obtained with the two-cycle Oechelhaeuser and Koerting engines are noteworthy. Professor Meyer states the principal difference between the two- and four-cycle motors as follows:—In the four-cycle the delivery pump and working cylinder are so combined that the same cylinder serves during the first two strokes for admission and compression, and for the last two as the motor cylinder. In the two-cycle these functions are divided, and therefore about twice as much work can be obtained with the same working cylinder, but with the added complication of the pump. In the large engines now required, in which the size of the cylinder is a

* Mr. Bryan Donkin was present throughout these experiments.

difficulty, it is of real advantage to have two cylinders. The question whether two-cycle engines are more economical and simpler can only be decided by tests and experience. From a theoretical point of view, the processes of combustion and work are as well carried out in two as in one cylinder, but rather more power is required to deliver and drive out the charge. The scavenging charge in the two-cycle type may, in Professor Meyer's opinion, be more desirable than to retain some of the products of combustion, as in the four-cycle. English writers seem agreed that the cylinder should be cleansed of the burnt products, but care must be taken that none of the fresh charge escapes through the exhaust. Each type of engine has its special characteristics, and is suitable for a given purpose.

One of the chief disadvantages of the four-cycle—namely, that it gives only one motor stroke in four—disappears when blast-furnace gases are utilised. For these such large powers are required that, as a rule, engines must be made with two cylinders, and thus an impulse is obtained per revolution, or with four cylinders, giving an impulse per stroke. The director of the Gas-Motoren Fabrik Deutz maintains the superiority of four-cycle over single-cylinder engines for large powers. If variations of speed of $\frac{1}{75}$ are allowed, the price is little less for two or four cylinders than for one; but if variations of $\frac{1}{125}$ only are permissible, as with motors driving dynamos, two-cylinder engines cost 75 per cent. less, and four-cylinder 60 per cent. less. The number of cylinders—one or four—does not seem to affect the consumption. For engines driving dynamos, the degree of uniformity, according to the latest opinion, should not fall below 1 in 150. This is a difficult matter to obtain in single-cylinder engines. Professor Meyer raises the point—also brought forward by Mr. Dugald Clerk—whether, since two cylinders are practically necessary in all large engines, the division of work is not better when these cylinders consist of motor and pump, instead of two motor cylinders.

An advantage especially noted by English writers is that, if blast-furnace gases can be utilised to produce power and save money, the manufacture of iron may be carried on under better conditions than at present. As long as it is the sole product of the furnaces, the fuel supplied is economised as much as possible. But, if more fuel were used and the heating value of the gas increased, more power could be obtained, while the production of iron would be improved. Since all the fuel supplied would be utilised, not only to produce better iron, but also, and perhaps primarily, to generate power gas, there would be no waste, as at present. In this respect, however, arrangements are now made to prevent the waste of gas from the top of the furnaces. About three-quarters of the gases generated should be made available for power. In

England, the volume or production of furnace gas is about 170,000 cubic feet per ton of pig iron smelted, or per ton of coke used. Thus, an engine burning 100 cubic feet per I.H.P. hour would give the equivalent of 1,700 H.P. per ton of pig iron.

Probably the greatest future for the utilisation of these gases will be in the storage of electric energy, transmission, and motive power for electric traction. It is even possible that by these means some of the furnaces now closed might again be started.

Summary.—The author had the advantage of studying many modern types of blast-furnace gas engines on the Continent. Most of them have dynamos on the crank shaft, generating electricity for power or light, as required, at different and distant parts of the iron works. Much still remains to be learnt as regards the best and most economical use to be made of these gases for power, and it is a large and most important new field for industrial enterprise.

As to the extent to which the gases charged with dust and other impurities must be cleaned, their treatment varies greatly in different works, according to the different fuels and ores used. The gases must be drawn continuously from the top of the furnace, and forced through the scrubbers and into the holders, and for this purpose various methods have been adopted—steam jets, fans, air propellers, pumps, exhaustors, &c. Time and experience will show the best system for each locality. Hitherto the blowing engines have nearly always been driven by steam. If the waste furnace gases are to be efficiently utilised, they should be burnt in gas engines driving the air compressors and pumps direct, as is done in some works, and especially at Seraing. Such an arrangement is much more economical than slow-running steam engines, with their cumbersome beams and cranks, the boilers to keep in order, the condensing water required, and all the usual long steam pipes, causing loss of heat by condensation of the steam, and a poor heat efficiency. On the other hand, blast-furnace gases can be passed through large pipes, without loss, to any part of the works where power is required. As will be seen from the tests given in Table No. 7, the heat efficiency in gas motors per B.H.P. is high, varying from 20 to 26 per cent. As to their commercial value, there is little doubt that, if capital be judiciously laid out on the best type of gas engines, it will yield a very good interest. Enterprising pig-iron masters ought not in the future to allow any of these gases to go to waste, but pass them all through gas engine cylinders, and thus obtain power in the most economical way, and at little cost.

Gas from Coke Ovens.—Among the various gases now available for power are those generated from the ovens in which coke for blast furnaces and foundries is made. It has been proposed, though the

suggestion has hardly yet been much applied, to use coke-oven gas to drive engines. When coal is thus converted into coke, if the bye-products be recovered and the gas utilised, a treble source of profit may be afforded. As shown by the analysis at p. 246, the gases obtained from these ovens are practically the same, when analysed, as lighting gas. The coke ovens may be placed close to the furnaces, and form with them and the gas engines one large power plant. Several engines are now worked with coke-oven gases, a description of which will be found under the different heads (see, in particular, Fig. 71). Messrs. Andrew, of Stockport, have made two double-cylinder engines, each of 200 H.P., to work with coke-oven gas, which have been running satisfactorily for some time. The gases require the same process of cleaning as blast-furnace gases.

In an able paper by M. De Keyser, the subject is thoroughly treated from an economic point of view. In his opinion, a great saving would be effected if blast-furnace gases were utilised to heat the coke ovens, and the gases from these ovens were conveyed direct to gas engines, and there burnt. One cubic metre, or 35·3 cubic feet, of blast-furnace gases will yield 0·252 H.P. when burnt in a gas engine, whereas 1 cubic metre of coke-oven gas will, under the same conditions, give 1·92 H.P., or nearly seven times as much power. As now worked, there is generally an excess of about 25 per cent. of gas, remaining over and sent to waste, after the requirements of the coke ovens have been met. If, from a battery of 50 ovens, this excess is burnt under boilers, it gives about 300 H.P.; but, if it be directly utilised in the cylinders of gas engines, it will yield 655 H.P. These gases have a high heating value, owing to their large proportion of hydrogen; very high compression, therefore, in the cylinder is not desirable. The coal supplied furnishes, on an average, 71 per cent. of coke by volume, and 270 cubic metres = 9,533 cubic feet of gas per ton of coal, or 380 cubic metres = 9,917 cubic feet per ton of coke produced.

Coke-oven plants are now working in Westphalia and elsewhere. MM. Koerting have a 1,200 H.P. electric power installation in Silesia, and the Deutz firm one of 675 H.P., both driven with coke-oven gas. For a test of a Borsig-Oechelhaueser engine, see p. 173. An interesting plant, the first on a large scale in Austria, was erected at the Theresa Mine, in Ostrau, in 1901. There are 120 coke ovens, the gas from which, after recovery of the ammonia, is utilised to drive three four-cycle 300 H.P. gas engines supplied by the Berlin Anhaltische Co. The engines are coupled direct to dynamos, and furnish the power required in the works. The gas has a heating value of 291 B.T.U. per cubic foot, and yields a heat efficiency of over 30 per cent.

Brown Coal Gas.—The following interesting particulars of a power

plant in Germany represents a class of work midway between the utilisation of coke-oven and of blast-furnace gases in engine cylinders. The engines, constructed by MM. Krupp, of Essen, are at the Emma Brown Coal Mine at Streckau, in North Germany. There are three four-cycle single-cylinder horizontal gas engines, each indicating 125 H.P., with a speed of 160 revolutions per minute. They are driven by the waste gases given off from brown coal when distilled to produce tar and coke. The gases, an analysis of which will be found in the table at p. 246, have a heating value of 2,750 to 2,800 calories per cubic metre = 308 to 313 B.T.U. per cubic foot, or a little more than half the heating value of lighting gas, and double that of power gas. They are drawn from the coke ovens by exhaustors, and led to the coolers, where the tar is deposited, then passed through purifiers to the gasholder. When burnt in a Bunsen burner the gas gives out sufficient heat to maintain the hot tube of a small auxiliary engine at the temperature of ignition. The power generated is used to drive two dynamos—one for lighting the mine, the other for the electric motors working the gas exhaustors, hauling gear, water pump, and a coal screening apparatus. In another plant near Halle there are two 100 H.P. engines, and another of the same size at Hoyerswerda. The Deutz firm have devoted attention to this class of work. The gases from brown coal briquettes, or loose coal, are usually generated in a producer in the same way as other power gas. In some places the heating value of the gas is not more than 180 B.T.U. per cubic foot, and the coal sometimes contains from 50 to 60 per cent. of water. The average consumption of this gas in an engine cylinder is 2·3 to 2·8 cubic metres = 82 to 98 cubic feet per B.H.P. hour.

Attempts have been made to utilise acetylene gas as a source of motive power, but they have not hitherto met with much success, owing to the highly inflammable character of the gas.

CHAPTER XIII.

THE THEORY OF THE GAS ENGINE.

CONTENTS.—Laws of Gases—Boyle's Law—Gay-Lussac's Law—Joule's Law of the Mechanical Equivalent of Heat—Thermal Units—Specific Heat—Carnot's Law—Perfect Cycle—Isothermal and Adiabatic Curves—Ideal Efficiency—Other Cycles—Indicator Diagrams—Entropy and Entropy Diagrams.

Laws of Gases.—No complete study of the gas engine is possible, unless it includes a knowledge, however slight, of the gas itself, or working fluid, the physical and chemical laws governing it, and the chief phenomena taking place in the cylinder of an engine. None of these phenomena are the result of chance. The laws controlling the action of gases have been accurately determined. The force of the explosion of gas in a cylinder seems, at first sight, impossible to regulate. But it can be determined with precision, and is always exactly proportioned to the pressure and temperature of the gas when admitted, and the amount of its dilution with air. Thus, if a certain weight of gas, composed of known chemical elements in a definite combination, and diluted with a given proportion of air, be admitted into a cylinder of known dimensions, its action can be accurately foretold, and the work which it is able to do estimated.

The term "working fluid" is applied to the medium of heat in thermal motors. It is equally correct to call it the "working agent," and the latter expression will here be used. No absolutely perfect gas is at present known—that is, a gas which obeys perfectly the theoretical laws, and cannot be condensed into a liquid by any change of temperature. But in the case of coal gas, air, or oil, the chief agents for the transmission of heat in internal combustion engines, the variation from a perfect gas is so slight that, for practical purposes, it may be neglected.

Of the different laws regulating the action of gases, two only are essential, in order to understand the phenomena in a heat engine. The first is known as Boyle's Law in England, and Marriotte's Law on the Continent. It was first propounded by Robert Boyle in 1662, and is as follows :—

I. **Boyle's Law.**—If the temperature of a gas be kept constant, its pressure will vary inversely as the volume it occupies.

This proposition defines the relation between three attributes invariably found in all gases—namely, their temperature, volume, and pressure, the latter being the force the gas exerts upon the walls surrounding it,

reckoned in lbs. per square inch. All the phenomena taking place in a heat engine are produced by varying one or other of these attributes—that is, by increasing or diminishing the temperature, the volume, or the pressure of a gas. Boyle's law may be illustrated by imagining a cylinder containing a piston, both perfectly tight. The piston is set half-way through the length of the cylinder, and gas admitted on one side of it; and the temperature of the gas being kept constant, the supply is next cut off. If the piston be then moved to its farthest limit, it will uncover the other half of the cylinder, and the available volume will be doubled. The gas will instantly expand, following the piston, and as no more is admitted, the same quantity will occupy twice as much space as before. But this increase in volume of gas will also be accompanied by a corresponding diminution in pressure. The force exerted by the gas on the piston will, at the end of the stroke, be half as much as before. If the space originally occupied by the gas be called one volume, and its pressure be taken as equal to that of the atmosphere, or in round numbers, a pressure of 15 lbs. on every square inch of the piston surface, the gas, when the piston has moved to the end of the cylinder, will occupy two volumes, but will exert a pressure of only 7½ lbs. per square inch upon the piston. The temperature being always the same, the products of the pressure and the volume will remain constant. To express Boyle's law differently—

$$\text{Volume} \times \text{pressure} = \text{constant}.$$

Now, let us suppose that the temperature be at the same time varied; quite different conditions are immediately introduced, and the law requires modification, necessitated by the introduction of a new factor, the action of which follows a second law. If heat be furnished to the cylinder described, and the temperature of the gas raised, without allowing the piston to move out, the gas will continue to occupy the same space as before, but the increase of temperature will cause the pressure to increase. The heat will force the particles of gas further apart, and the pressure or tension will rise until, if the temperature be continually increased without an increase in the volume, the gas will burst the cylinder. This expansion of gas through the application of heat, and its corresponding contraction when heat is withdrawn, have been carefully verified, and the degree of variation in volume or pressure, determined by experiment, has been found to be in exact proportion to the quantity of heat added to, or abstracted from, the gas. It forms the basis of the following second law of gases, called Charles' law in England, and the law of Gay-Lussac on the Continent.

II. **Gay-Lussac's Law.**—The pressure being constant, all gases expand $\frac{1}{273}$ part of the volume they occupy at 0° C. for every rise of 1° C. in their temperature. The law may be stated differently thus:—

Suppose a gas at 0° C. is at constant volume in a closed vessel, and exerting a pressure of 273 lbs. per square inch. For each degree Centigrade added to its temperature, the pressure of the gas will increase 1 lb. per square inch. If, therefore, its temperature be raised 10° the pressure will be 283 lbs. per square inch. The converse of the law also holds good. If the volume remains constant, the initial pressure of a gas at 0° C. diminishes by $\frac{1}{273}$ part for each degree Centigrade by which its temperature is lowered. Therefore, if a gas at 0° C. be reduced 1°, it will contract by $\frac{1}{273}$ part of its volume, and if it were possible to continue the process, and to lower gradually the temperature of the gas 273° C., a point would be reached, called the "absolute zero," at which the gas would theoretically possess neither volume nor pressure. In practice, however, this limit is never reached, a "critical" point intervening, at which the gas alters its physical condition and liquefies, when the law as to gases naturally holds good no longer. According to the law of Gay-Lussac, more heat could not be abstracted, even if the lowest limit of temperature were not reached, because the gas would have no further power of contraction, and therefore of diminution in pressure.

It is very difficult to reduce a body to this extreme of cold, although in recent experiments it has practically been done. The "absolute zero" —viz., 273° below 0° C. and 461° below 0° F.—is, however, the basis of all calculations of temperature in scientific work. The zeros fixed by Fahrenheit, Réaumur, and Celsius are all arbitrary determinations, below which temperatures continually fall, but they cannot be used as the original starting point for measuring heat.* In calculating the heat in an engine, the temperatures are usually measured from the absolute zero, or ordinary temperature Centigrade + 273°. Now in the first law of gases there are variations in only two characteristics of a gas to be considered. In the second law three variables occur, and the relation between the three is expressed thus :—

$$\frac{v \times p}{T} = \text{Ratio or R.}$$

Put into words this formula runs :—The volume v multiplied by the pressure p of any gas, and divided by the absolute temperature T, are equal to a certain fixed ratio, R. The same law may, of course, be expressed thus :—

$$v \times p = R \times T.$$

The value of R for air is 29·64.

* The centigrade scale fixed by Celsius has been practically adopted in Europe and America for scientific work. It is often used in this book, in order not to confuse the student passing on to other and more elaborate theoretical works, in which he will find no other scale of temperature given.

This expansion of a gas $\frac{1}{273}$ of its volume for every degree Centigrade added to its temperature, is equal to the fraction 0·00367, called the coefficient of expansion. The term "coefficient" signifies a fixed quantity or mean value, accurately determined by experiment, and applying equally to all bodies possessing the same properties, and under the same conditions. If the amount of heat added to any gas be known, the degree to which it will expand can be exactly calculated by this coefficient. As it increases in pressure or expands in regular proportion to the heat added, it is evident that there must exist some fixed relation between the expansion of the gas and the temperature producing it. This relation forms a link between the laws of gases we have just been considering and those governing the action of heat, and furnishes a good example of the first and most important Law of Thermodynamics, the Mechanical Equivalent of Heat. It may be briefly stated thus :—

I. **Joule's Law—Mechanical Equivalent.**—Whenever heat is imparted to, or withdrawn from a body, energy is generated in proportion, or an equivalent amount of mechanical work is done by the body, or upon it by external agency. The proportion between the heat absorbed, or given out, and the work performed is always the same.

This law, which has given a new direction to scientific thought during the last half century, was foreshadowed by Count Rumford and Sir Humphry Davy, and discovered almost simultaneously in England by Joule, in Germany by Meyer, and in France by Hirn. The priority is usually ascribed to Joule, who published the results of his experiments in 1843, and the law is known in England as the Law of the Mechanical Equivalent of heat, or briefly as Joule's Equivalent. It is twofold in its operation and effects, and may be expressed as :—heat is a form of energy, or mechanical energy (work) may be converted into heat according to a definite law.

To explain it we will again use our illustration of a cylinder with an air-tight piston, containing a given volume of gas. As long as the temperature of the gas does not vary, its volume and pressure have been proved to stand to each other in exactly inverse ratios. As the one increases, the other decreases. If heat be added, the gas expands, the pressure rising in exact proportion to the increase in heat. It is the law of the mechanical equivalent which explains the reason of this increase in expansive power. Heat has been put into the gas, and disappears as heat, to reappear in some other form. Nor can it be otherwise. The law of the mechanical equivalent is a necessary deduction from the principle that nothing in nature can be lost or wasted. All the heat imparted to the gas must be found again, either as heat, or transformed into some other form of energy. In the case of our cylinder and piston,

all the heat will be changed into work, and will be absorbed in producing the expansive force of the gases driving out the piston. Were there no piston, and the cylinder open at one end, work, since it must be done by the expansion of the gases, would be done on the atmosphere. In no case can the heat imparted to the gas be lost. Either it is represented by the expansion of the gas, or carried off by radiation to the conducting substances surrounding the cylinder.

The earliest and simplest example of heat transformed into mechanical energy is shown by a cannon, which is really a primitive form of heat engine. The bore of the cannon represents a cylinder, the bullet is acted upon in the same way as a piston. A solid combustible is used to produce inflammable gas, but the effect is the same as in a gas motor. Heat applied to this combustible or powder causes it to explode, and the force of the explosion, or expansion of the gases generated, drives out the bullet with great velocity. Not only can heat be thus transformed into actual work, but the converse proposition that energy may be translated into heat has been demonstrated by many careful experiments. Both are mutually convertible forces, and this may be verified by suddenly arresting the progress of the bullet. The energy of motion imparted to it by the heat of combustion and not yet expended, is immediately retransformed into heat, and the bullet is found to be much hotter than if it had been allowed to continue its course till its velocity was spent. Sir Humphry Davy demonstrated the truth of this proposition in another way, by his celebrated experiment of rubbing two pieces of ice together in a vacuum, without change of temperature. Water was produced, showing that the ice was partially melted, and the heat required to effect this change of state could only have been obtained by friction—that is, by mechanical energy or work, as no heat had been added externally to the ice.

The theory of the mechanical equivalent is equally applicable, whether a gas be heated or cooled. If heat be imparted to it, and the gas allowed to expand, the particles are driven further apart; if heat be abstracted they shrink. Work will be done *on* the gas by contraction, instead of *by* the gas through expansion. But if a gas be compressed at constant temperature, and no heat abstracted, work being done on it, and the gas caused to diminish in volume, heat will be stored up, and the temperature of the gas raised. The energy of motion or mechanical work of compression of the particles is transformed into heat. If, however, the heat is carried off in proportion as it is evolved by contraction, the gas will, as has been shown, gradually decrease in volume, in temperature, and in pressure, until the point of absolute zero is reached. In this way the law of the mechanical equivalent confirms the existence of an absolute zero. If it were possible for the gas to exceed this limit in

any one of its three characteristics, the fundamental law of thermodynamics would be violated. If it could decrease still further in volume, work would be done in contraction without any corresponding diminution in temperature, and we should have energy without heat. The two aspects of the law in its application to gases are, expansion by the addition of heat, and contraction by the withdrawal of heat. In a heat motor the first is called positive, and the second negative work. It is with the effect produced by external work that the theory and practice of heat engines are chiefly concerned.

Thermal Units.—The proportion between the heat added and work done being a fixed quantity, it is possible to determine accurately the work theoretically performed for a given amount of heat supplied. The two are linked together in practice, and the relation in which they stand to each other is expressed in the following way:—In England it is usual to adopt as the unit of Heat the "British Thermal Unit" (B.T.U.), or the amount of heat which will raise 1 lb. of water 1° F., and if this unit of heat be applied to a body, it is equivalent to the work of lifting 778 lbs. 1 foot in height, or a weight of 1 lb. a distance of 778 feet. On the Continent the unit of heat is called a "*calorie.*" One *calorie* represents the amount of heat required to raise the temperature of 1 kilogramme of water 1° C., and if this quantity of heat be converted into work, it will lift 425 kilos. through 1 meter, or 1 kilo. through 425 metres. The unit of measurement of work is called foot-pound in England (ft. × lb.), and a kilogrammetre abroad (kilo. × metre). The difference lies only in the respective units of weight and temperature employed here and on the Continent.

The measurement of the exact relation between heat and work was determined by James Prescott Joule, after long and careful experiments. The apparatus he principally made use of to verify the law of the mechanical equivalent consisted of a closed copper vessel filled with water. Within it were revolving paddles attached to a vertical spindle. The spindle and paddles were made to rotate by means of a cord passing over a pulley connected to a weight. When the weight fell, the spindle rotated, causing the paddles to revolve and to agitate the water, and heat was produced by friction between them. The rise in degrees of temperature of the water was found to be exactly in proportion to the distance in feet passed through by the weight, multiplied by the number of lbs. it weighed. From these and many similar experiments with water and gases, Joule deduced his great law.

Specific Heat.—All bodies have not the same capacity for absorbing heat. Those which are heated without changing their physical state require less heat to raise their temperature than bodies which are converted, during the rise, say from liquid to gaseous. A large quantity of

heat must, for instance, be imparted to water, because, after it has absorbed a certain amount, it ceases to be a liquid, and becomes a gas, steam. Specific heat is the quantity of heat necessary to vary the temperature of any body through one degree, the quantity of heat required to raise or lower the temperature of an equal weight of water through one degree being taken as the unit. Water is universally adopted as the standard of comparison, and its specific heat being greater than that of most other bodies, their specific heats are expressed in fractions. For example, a B.T.U. represents the amount of heat required to raise 1 lb. of water 1° F., therefore, 100 heat units will raise its temperature 100° F. The specific heat of mercury is ·03332. To raise 1 lb. of mercury through 100° F. will require ·03332 × 100° × 1 lb. = 3·332 heat units. The specific heat of mercury is, therefore, about $\frac{1}{30}$ that of the same weight of water, which requires thirty times more heat units to bring it to the same temperature. Specific heat has been ably illustrated by Mr. H. Graham Harris under the similitude of "appetite."*

Further, the specific heat of the same body will vary according to circumstances. If the body remains under stationary conditions, its specific heat will be less than if its condition changes. To return again to the cylinder containing a given volume of gas. As long as the gas remains inert or passive, and its volume does not vary, it possesses a definite specific heat, which being known, the quantity of heat to be added, to raise it to a certain temperature, can be calculated. But if the piston is driven out, by reason of the expansion of the gas which, according to Gay-Lussac's law, increases in volume by $\frac{1}{273}$ for every degree rise in temperature, work will be done, and heat will in consequence be expended. More heat will, therefore, be required to heat the gas—that is, its "heat appetite" will be greater when it has forced out the piston than before. Under the first condition, the heat absorbed by the gas is defined as its "specific heat at constant volume," because, the piston being stationary, neither the volume of the cylinder nor that of the gas has varied. As the piston moves towards the end of the stroke, the volume is increased, and expansion takes place. The heat of the gas is then called its "specific heat at constant pressure," because, while the volume of the cylinder has varied, the pressure over the piston area has been constant. The specific heat of the gas at constant pressure will be higher than at constant volume, and the difference between the two represents the work done per lb. of gas. That is to say, the increase of specific heat in the gas denotes the amount of heat required to maintain

* See Mr. Harris's Cantor Lectures on "Heat Engines other than Steam," delivered before the Society of Arts, May, 1899, to which the student is referred for an exceedingly clear elementary treatment of the subject.

the requisite pressure on the piston, and therefore the work it has performed.

The ratio between these two specific heats is of great importance, and has frequently to be employed in calculations of efficiency or mechanical energy in a heat engine. It varies slightly as given by different authorities, but is usually reckoned at 1·39 by foreign, and 1·408 by English writers. The following table, taken from Regnault, Grashof, Ayrton and Perry, and others, gives the specific heats of various gases at constant pressure and constant volume, and their ratio :—

TABLE OF SPECIFIC HEATS OF GASES (from various Authorities).

	Specific Heat at Constant Volume.	Specific Heat at Constant Pressure.	Ratio γ
Air at ordinary temperature,	0·168	0·237	1·41
Dry air (Rankine's constant),	0·169	0·238	1·40
Steam,	0·369	0·480	1·30
Hydrogen,	2·406	3·409	1·41
Nitrogen,	0·173	0·243	1·41
Oxygen,	0·155	0·217	1·40
Carbon monoxide,	0·173	0·245	1·41
Carbon dioxide,	0·171	0·216	1·26
Methane,	0·470	0·593	1·26
Mixture of air and gas—12·26 vols. air to 1 of gas,	0·196	0·268	1·37
Products of combustion (vols. before combustion, 1 : 8·18),	0·192	0·264	1·37
Coal gas diluted with 5·76 vols. air, 4·5 vols. products—before combustion,	0·182	0·249	1·38
Coal gas diluted with 5·76 vols. air, 4·5 vols. products—after combustion,	0·188	0·258	1·36

This ratio, 1·4, is usually expressed by a symbol, which we will call γ. The symbol represents the difference between the specific heat of the gas at constant volume and that at constant pressure. For example, for air $0{\cdot}237 - 0{\cdot}168 = 0{\cdot}069$ B.T.U. = the increase in the specific heat at constant pressure, when external work has been done, over that at constant volume, when no such work has been done.

The foregoing laws and their results show the way in which mechanical work is obtained in a heat engine. The whole principle of converting heat into work depends on the heat added to the gas, and its effect upon the volumes and pressures. Theoretically, the greater the quantity of heat added, the more work will be done on the piston, because the pressure will be higher, and expansion greater. But to obtain a maximum of work, all sources of waste must be guarded against. The temperature of the gas should, at the outset, be raised to its highest limit, as much heat as possible utilised in expansion, and as little as

possible wasted. It is necessary to have at our disposal a source of heat and a source of cold—the one to impart, the other to withdraw the heat. These conditions bring us to the second law of thermodynamics, known as Carnot's, because it was first laid down by him in 1824. It is as follows:—

II. **Carnot's Law.**—If heat is exchanged at constant temperature between a source of heat and a source of cold, the proportion between the quantity of heat furnished and that abstracted depends only on the absolute temperature (Centigrade + 273°), and not on the nature of the body to which the heat is imparted. The expression "constant temperature" means, not that the amount of heat present does not vary, but that it varies only in proportion to the work done, so that the temperature is not affected. This law, when applied to the phenomena in a heat engine, results in what is called a "perfect cycle." It supposes the whole difference of temperature between the "heat" source and the "cold" source to be utilised in doing work, and no heat to be carried off and wasted—a condition of things, of course, impossible in practice.

But where, it will be asked, is the necessity for a source of cold? Since the more heat is added to a gas, and absorbed in expansion, the more work will be done, why should not the whole of the imparted heat be thus utilised, and none remain to be withdrawn? The reason is that, as there is an absolute zero to which no gas can ever be cooled, therefore the whole heat can never be converted into work. In a motor driven by water falling from a given height, to turn to practical account all the energy stored up in the water, it should fall to the centre of the earth! As it can only descend a given distance, from whatever height it may come, only a certain proportion of its energy can be utilised. The same law applies to the fall in temperature of a heat engine. It is only within certain limits that this range of temperature can be varied, but the wider the limits, the greater the force or energy obtained. To enlarge these limits as much as possible, heat must be added, and the temperature of the working agent raised at the beginning.

This fall in temperature of a gas, and the corresponding loss in pressure upon the piston, takes place inside the cylinder of a heat engine. To calculate the work done, it is very desirable to have a record of the actual pressures during the forward stroke. This is obtained by an instrument called an Indicator, which is placed in direct communication with the cylinder, and gives a diagram tracing the varying pressures on paper. The curve traced first rises abruptly, marking the sudden rise in pressure due to explosion at constant volume, and then falls gradually with decrease of cylinder volume, showing how the pressures slowly decrease as the piston is driven out. To exhibit clearly the proportions

between the loss of heat and pressure and the work done during the changes in the gas, two theoretical curves are used.

1. The first is known as the **Isothermal**, and signifies from its name the curve of equal temperatures. Here the piston of a cylinder moves out, by the expansion of the gas produced by the addition of heat, and the effect of the expansion is represented by a curve in which the temperature is constant, and the pressure alone falls. It has been proved that, where work is done on the piston by a gas, the temperature must fall; the isothermal curve, therefore, is based on the assumption that heat is added to the gas, to compensate for that lost in expansion. The curve is never obtained in practice, but it is occasionally approached when the process of expansion in a heat engine is reversed, and heat is refunded to the gas by compression. In either case, the volume of the gas varies in inverse ratio to the pressure.

2. The **Adiabatic** is another theoretical curve, representing the fall in temperature when heat is neither added to nor abstracted from the working agent, but expended only in doing work by expansion on the piston. The term is derived from a Greek word signifying "impenetrable," and was first applied by Rankine. The nearer the diagrams of pressure approximate to this curve, the more perfectly will the engine utilise the heat imparted to the gas. If the difference in the specific heat of a gas at constant volume and at constant pressure be taken as representing the heat turned into work, the ratio between the two is graphically shown by the adiabatic curve. Since no heat is added or withdrawn, the temperatures do not enter into the definition, and the curve may be expressed as a function of volumes and pressures, thus $p \times v^{\gamma}$ is constant, or :—The pressures of the gas, multiplied by the volumes, raised to the power of the ratio of the two specific heats, give a constant product.

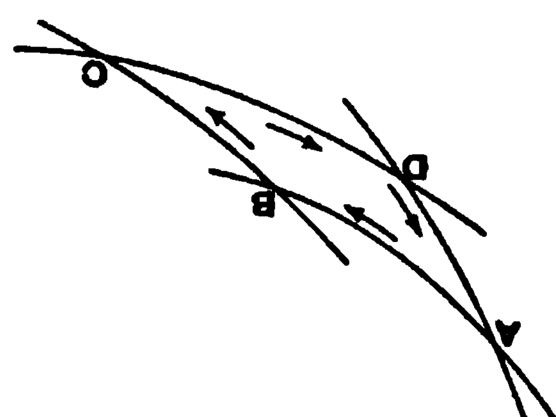

Fig. 114.—Graphic Representation of Carnot's Law.

Carnot's Cycle.—Fig. 114 gives a graphic representation of Carnot's law, which, plotted out in the shape of the curves just described, forms a perfect or closed cycle. Here the working agent, after passing through the phases of the addition of heat, expansion, abstraction of heat and compression, is brought back theoretically to its original condition. The processes of heating and cooling can be continuously repeated, or the sequence of operations reversed. The necessity for a source of cold is manifest. If the working agent is a gas, it must be cooled to its initial temperature, and this cannot be accomplished by the work of expansion alone. It has hitherto seldom been found possible in any engine to allow the gases to expand to atmosphere, and thus use in work all the

heat generated. The cycle (Fig. 114) is formed of two isothermal and two adiabatic curves, and shows their theoretical forms on a small scale. The gas first receives heat from the source of heat, and expands along the line A B with increase of volume. As the temperature is not allowed to fall, the curve is an isothermal. From B to C there is another increase of volume. The gas expands without the addition of heat, the temperature falls in consequence only of work done, and this line shows the curve of adiabatic expansion. At C communication is opened with the source of cold, and heat is supposed to be withdrawn along the line C D to the same extent as it was added from A to B. The volume is here diminished, and the line C D is again isothermal. From D to A the gas is compressed without heat being abstracted, and consequently increases in temperature, in proportion to the work done upon it. Compression is adiabatic, and at the end of the cycle the gas has returned to its original volume.

Actual indicator diagrams of gas engines do not usually consist of four curves. There is first the line of addition of heat, nearly vertical, then the expansion line, conforming more or less to the adiabatic, and lastly the exhaust, or discharge of the remaining heat to the cold source, which is generally nearly horizontal. (See the diagrams of the various engines given in several places.)

It is a condition of the Carnot cycle that heat is only added when the gas is at its highest temperature, before any work has been done, and abstracted at its lowest, after expansion. Since the mechanical energy obtained is in strict proportion to the heat imparted to the working agent, this ideal or typical cycle furnishes and utilises the largest amount of heat. Hirn, the great French *savant*, says:—"It must be evident that this closed cycle has been designed to afford a maximum of work. The heat given up by the source of heat has been employed solely to produce work, and a maximum has therefore been obtained. The heat sent on to the refrigerator has been evolved as economically as possible, since the work has produced no variation of temperature. The object of the other two operations (along the curves C D and D A) has been solely to cause a fall and a corresponding rise in the temperatures and pressures." Thus the cycle obtained is perfect, since the heat supplied from the source of heat and by compression, is equal to the heat expended during expansion and conveyed to the refrigerator. Therefore the working agent or gas is at the close of the cycle in the same condition—that is, at the same temperature and pressure—as at the beginning. Clearly the source of heat and the refrigerator act by alternately expanding and contracting the working agent or gas.

Carnot's Formula.—This cycle may be expressed by the following

formula, in which Q represents the quantities of heat supplied by the source of heat, and q the quantities passed on to the source of cold, or, in other words, rejected because they cannot be utilised. T_1 is the absolute highest, and T_0 the absolute lowest temperature, and E what is called the theoretical efficiency of the engine:—

$$E = \frac{Q - q}{Q} = \frac{T_1 - T_0}{T_1} = 1 - \frac{T_0}{T_1}$$

On this theoretical basis the heat efficiency is calculated between the highest and lowest temperatures.

Numerical Example.—In the Atkinson 9 H.P. engine, tested by the Committee of the Society of Arts in 1888, the temperature of the gases (Fahr.) on entering the cylinder was 567° absolute (T_0), and their temperature at the moment of highest explosion 2,990° absolute (T_1). The theoretical formula of efficiency is—

$$E = \frac{T_1 - T_0}{T_1} = \frac{2{,}990^\circ - 576^\circ}{2{,}990^\circ} = 0{\cdot}80$$

The student will here be inclined to ask what, in this simple formula, becomes of the ratios of specific heats at constant volume and pressure, the coefficient of expansion, and the other complex attributes of expanding gases already described. They are here expressed in their simplest forms, and nothing is taken into account except the quantities of heat, and the temperatures. Now the temperatures in a heat engine are, except the initial temperature of the gases, usually deduced from the pressures and volumes. It is in making these calculations that the specific heat of the gases under different conditions, the ratio of expansion to increase of temperature, and other modifying circumstances have to be considered. To calculate the work of an actual engine four or five temperatures, with their corresponding variations of volumes and pressures, must be determined and calculated from experiment. The above formula gives the method of calculation, not the process by which it has been arrived at.

Ideal Efficiency.—Both the highest and lowest temperatures, T_1 and T_0, in a heat engine, and the maximum amount of work which may be obtained from it, are restricted within certain limits. Even in this perfect cycle, it has been proved to be impossible for the lowest temperature, T_0, to fall below a given point. The highest, T_1, is almost as rigidly defined by the phenomena of dissociation, the power of the cast-iron cylinder and the lubricant to resist great heat, and other circumstances. A perfect engine, therefore, is not one giving unlimited expansion, and 100 per cent. of work, but one which turns all the heat supplied to it between the limits T_1 and T_0 into work. This is its maximum utilisation of heat, or what is called the "ideal efficiency" of

the engine, which we will now compare with the practical efficiency, or the amount of heat a working engine can actually convert into motive power.

To obtain the highest efficiency, an ideal engine must be supposed to work with—1. A perfect gas, the volumes and pressures of which conform to the laws of Boyle and Gay-Lussac. A study of the chemical constituents of gases, and their action during combustion, shows that this conformity is never obtained in the cylinder of a gas engine. 2. No friction of the working parts. Friction generates heat, and heat we know is the equivalent of energy. Part, therefore, of the mechanical energy of the motor, which in an ideal engine cannot be taken into account, is absorbed to produce this heat. 3. No radiation or conduction of the heat through the walls of the cylinder containing the gas. Of course, it is impossble to have a vessel of this nature—that is, an absolute non-conductor of heat. As soon as the gas is at a higher temperature than the surrounding atmosphere, a certain portion of the heat must be transmitted by radiation to the colder external air. 4. Lastly, expansion must be prolonged till the temperature and pressure of the gases is the same as at admission. This is also impossible. The temperature of the gases is always much higher than T_0, and therefore much heat is discharged at exhaust.

Other Cycles.—In the diagram shown at Fig. 114 the curves A B C D enclose an area representing not only the heat supplied, but the amount of work done by a heat engine. The curves, and therefore the shape of the area, may, however, vary according to the way in which the heat is supplied to, and withdrawn from, the engine, or according to the expansion and compression of the charge. Figs. 115 and 116 repre-

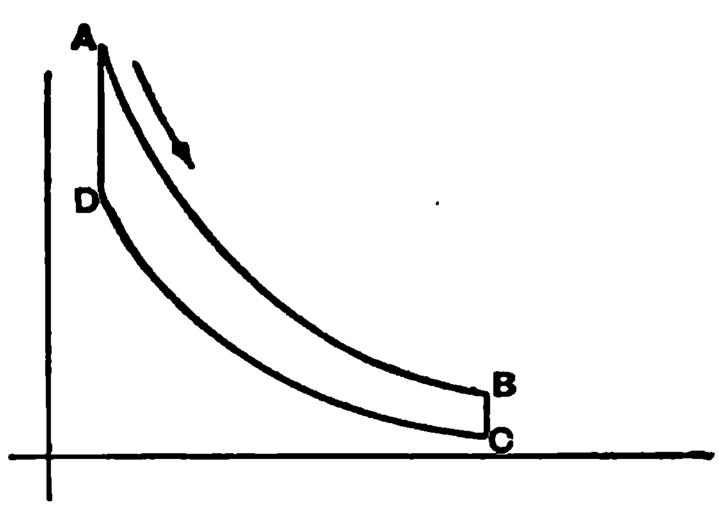

Fig. 115.—Stirling Cycle—Constant Volume.

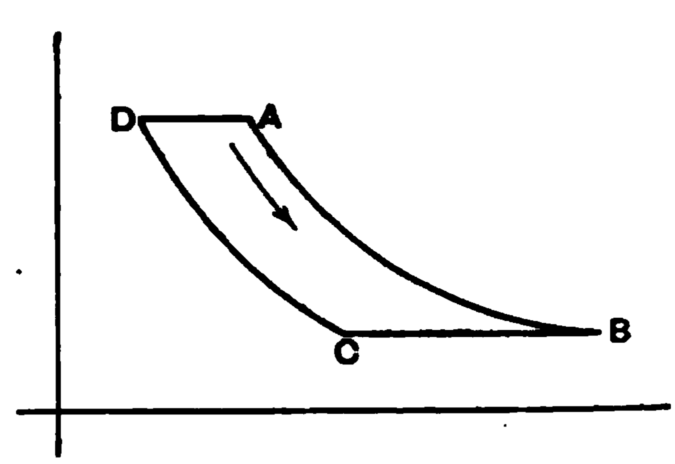

Fig. 116.—Ericsson Cycle—Constant Pressure.

sent two other theoretical cycles known, the first as Stirling's, the second as Ericsson's. Though the curves are here of different lengths, they are, like those forming Carnot's cycle, theoretically perfect, and form the boundaries of an equal area. Heat is added in both cycles from D to A, and abstracted from B to C, and these lines are designated by Professor

Witz "isodiabatic," or lines of equal transmission of heat. The curves A B and C D are no longer adiabatic, but isothermal. The first represents the whole of the useful conversion of heat into work at constant temperature; in the second the heat is refunded, and the same amount restored to the gas by compression as was expended in work. The lines B C and D A are straight, parallel in the one case to the vertical line, called an ordinate, at the left hand of Fig. 115, and in the other to the horizontal line (abscissa) at the bottom of Fig. 116. The areas enclosed within these curves form the bases of calculation of all diagrams representing work done in any heat engine. The ordinates in such a diagram are in proportion to the pressure in the cylinder, the abscissæ to the length of stroke.

The horizontal lines in these figures represent the volumes of the cylinder. Along this line the piston may be said to travel, driven forward by the expanding force of the gas, and the farther it moves to the right the larger the cubic area of the cylinder exposed. If the piston is moved half way along the horizontal line, half the volume of the cylinder, reckoning from the dead point, will be uncovered by it. The horizontal line in an indicator diagram, therefore, represents volumes of the cylinder or lengths of stroke, and distances along it are calculated in feet or metres. The vertical line in the figures, and in indicator diagrams of heat engines, represents the pressure of the gas obtained by the addition of heat, and is usually divided into sections reckoned as so many lbs. pressure per square inch of piston surface. So that we get horizontally *feet*, and vertically *lbs.*, or feet × lbs. = work in proportion to area of diagram.

Indicator Diagrams.—It will make the study of the heat engine easier to the student if we describe here how an actual indicator diagram is taken, and the kind of instrument used to trace it. The same type of apparatus is employed in gas, oil, and steam engines. It consists of a small piston and cylinder in direct communication with the inside of the motor cylinder; the piston is forced up or down with the varying internal pressures produced by the expansion of the gas. To the upper part of this piston is attached a small pencil. A drum covered with paper is made to travel to and fro at the same relative speed as the motor piston. The apparatus is so arranged that as the drum moves horizontally, the pencil of the indicator piston moves vertically. The pencil goes up and down in proportion to the cylinder pressures (lbs.) and the paper travels to and fro in proportion to the stroke (ft.). These two movements are brought in contact, and the pencil traces a diagram on the paper (see Fig. 122, p. 309). The vertical lines of this diagram represent lbs. pressure per square inch on the piston surface, and the horizontal lines feet travelled through by the piston.

The pressures and the volumes of a gas being known from the indicator diagram, the temperatures are usually calculated from them. To determine these temperatures in a gas engine is, however, a difficult process, because many scientific men are of opinion that, at the moment of explosion, the gases in the cylinder are not at a uniform temperature throughout. In the two closed cycles given in Figs. 115 and 116 the lines of addition and abstraction of heat, D A and B C, are in the first figure parallel to the pressures, in the other to the volumes. This means that in Fig. 115 the heat is supposed to be added from the source of heat and withdrawn, while the volume remains constant, and the piston stationary at either end of the cylinder. In Fig. 116 the heat is added and abstracted while the pressure of the gas remains constant, the piston being forced out, and the volume of the cylinder increased. More heat must be added for a given rise of temperature than in the other case, because a certain amount is expended in driving the piston. The two figures exhibit, under another form, the ratios of specific heat at constant volume and at constant pressure.

It is from the indicator diagram, therefore, or diagram of pressures, that it is possible to know theoretically how much heat enters an engine (Q) and how much leaves it (q), and to determine

$$\text{Efficiency} = \text{E} = \frac{\text{Q} - q}{\text{Q}}.$$

But this formula will not express the actual work done, or at least the determination of Q and q will, under these conditions, be a matter of great difficulty. Some of the various deficiencies in the cycle of a working engine have already been mentioned. There has hitherto always been a wide discrepancy between the theoretical possibilities of a heat motor, and the actual results. To discover the reason of this difference, complete investigations and experiments are necessary. Not only do we need to know the total amount of heat supplied to an engine, and what becomes of it, but how and when the heat is added. Science has already done much to elucidate the first point; our knowledge of the second is still somewhat elementary.

Entropy and Entropy Diagrams.—The following account of this abstruse subject is taken from an article by the author in *Engineering*, 3rd January, 1896, forming part of a translation of a paper by Professor J. Boulvin, of Ghent University :—

In the calorimetric study of an engine, the exchanges of heat taking place between the fluid and the internal walls of the cylinder should be determined, and for this process the graphic method will be found of great use. For instance, the heat supplied to the cylinder being represented by a given area, the latter may be divided into several parts, one of which will represent the heat converted into work on the piston,

another the heat given up to the walls, or dissipated in other ways, and thus a kind of graphic heat balance is obtained. If the heat not utilised in work be further subdivided into its component parts, or into loss of heat due to the water jacket, to the exhaust, and to radiation, it will be possible to show exactly how the heat supplied to the engine has been expended.

The indicator diagram, which gives changes of pressures and volumes, cannot be used for this purpose, since the area thus obtained marks only the work done on the piston. To show the movements of heat, they must be converted by calculation into mechanical energy for each portion of the stroke, and this is the way in which the subject has lately been treated by various scientific authorities. The new system furnishes a direct graphic representation of the heat supplied to a body, by taking temperature and entropy as the characteristics of its condition. For ordinary purposes, it will be sufficiently clear if the following explanation of the term "entropy" be accepted:—

Let us suppose that an infinitesimal quantity of heat, $d\,Q$, is supplied to a body at the absolute temperature T; the increase of entropy in this body is defined as $\frac{d\,Q}{T}$, or entropy multiplied by absolute temperature equals the number of calories. Thus $\frac{d\,Q}{T}$ may be considered as a weight which, falling from the height T, will produce the energy $d\,Q$, since $\frac{d\,Q}{T} + T = d\,Q$. If the increase or successive additions of $\frac{d\,Q}{T}$ be plotted as abscissæ, and the different absolute temperatures T as ordinates, a curve will be obtained, the area of which will represent the sum of all the elements $d\,Q$—that is, the heat supplied. The movements of heat can be deduced from the particular form of the curve thus obtained. Thus if the fluid studied is the mixture of gas and air expanding in a cylinder, the curve will show by its shape if the heat is passing from the mixture to the walls, or in the reverse direction.

An example of the entropy diagram, as applied to a gas engine, taken from Professor Boulvin's book,* is given at Fig. 117. It is a diagram of Entropy, or Heat, worked out from the Society of Arts' Trials, 1888, on a Crossley-Otto engine, and should be compared with the indicator diagram at p. 94. The latter, sometimes called the $p\,v$ diagram,† is necessary to get the I.H.P., and upon it and other data the entropy diagram is based, but the I.H.P. diagram gives no results for exchanges of heat and temperature, which are so important to investigate, and it is not a complete index of what takes place in an engine cylinder. The

* *Cours de Mécanique Appliquée*, vol. iii., p. 173 (*Machines Thermiques*).
† $p\,v$—*i.e.*, pressures—volumes.

area of an entropy diagram gives thermal units. For the method of drawing it see the paper already referred to, and M. Boulvin's book, vol. iii., p. 41. Captain Sankey determines each point from the intersection of the lines of equal pressure and equal volume. The term "entropy" was first adopted by Clausius to denote the integral $\frac{dQ}{T}$. The method of drawing entropy diagrams is first claimed for M. Belpaire in 1872, and is described by Schöttler (p. 109), who lays down clearly the difference between the diagrams of heat and of pressure, and by Professor Zeuner. In England the subject has been treated by Mr. Macfarlane Gray, who calls entropy the $\theta\ \phi$ diagram.* Professor Stodola says that by means of

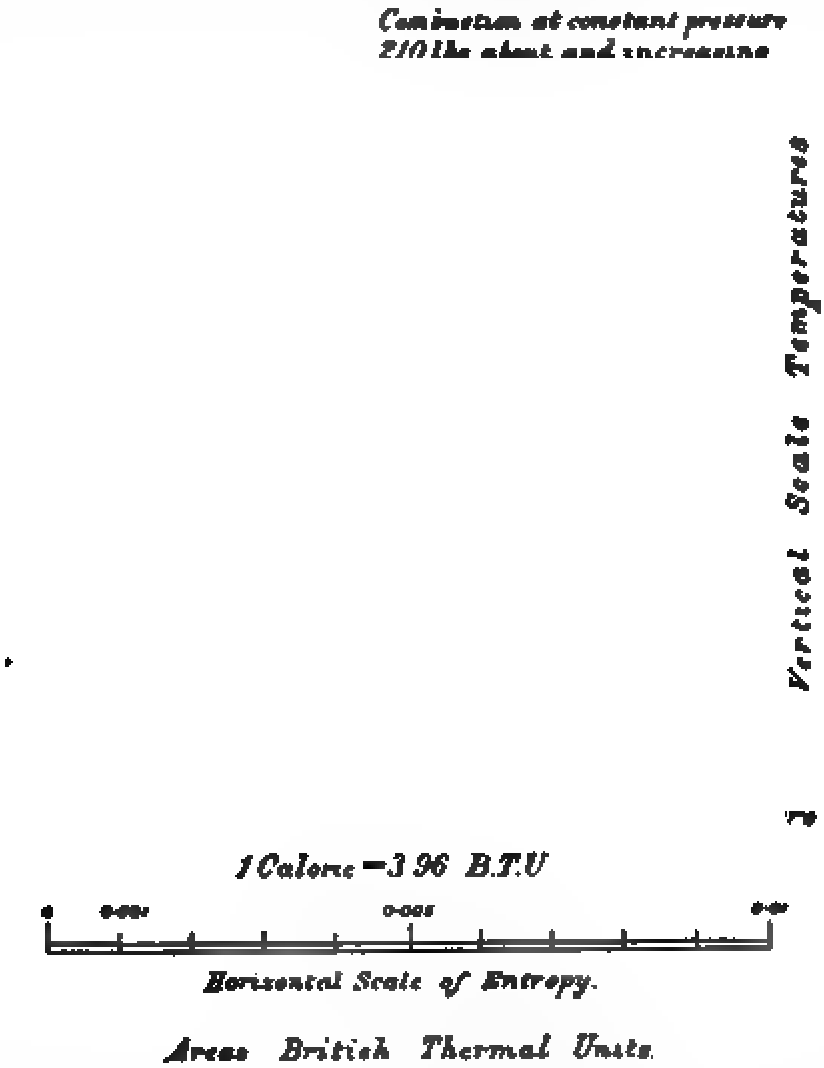

Fig. 117.—Entropy Diagram.

a properly constructed entropy diagram, all questions having reference to the cycle in gas engines can be solved easily and quickly by the graphic method, and with sufficient accuracy for practical purposes. To the engineer it affords the best way of handling the science of thermodynamics. German scientists have derived from it a new word, namely, "heat toning," which may be described as the excess of energy set free

* See *Proceedings of the Institution of Mechanical Engineers*, July, 1889.

by chemical combination, the final products being cooled to the same temperature as the original. The tones of heat may best be determined by studying a cycle of combustion at constant volume.

Note.—Although this chapter is headed "Theory of the Gas Engine," it practically applies equally to engines driven with oil vapour, spirit, alcohol, or any other forms of internal combustion motors. All these work in the same way as gas engines, the only difference being the agent of heat furnishing the explosive power.

CHAPTER XIV.

THE CHEMICAL COMPOSITION OF GAS IN ENGINE CYLINDERS.

CONTENTS.—Atoms and Molecules—Chemical Symbols—Atomic Weights—Molecular Weights—Specific Heat—Chemical Equations—Heating Value of Gas—Calorimeters—Berthelot-Mahler—Junkers—Higher and Lower Heating Value of Gas in a Calorimeter—Composition of Coal Gas—Calorific Value of Coal Gas and of other Gases—Composition of Power Gases.

IN the preceding chapter we have seen that a gas engine is simply one form of heat engine, and that its object is to transform heat into work through the medium of gas—the working agent. We now want to know, further, how this process is carried on with maximum efficiency, so that the largest possible proportion of the whole heat we add to the agent may be converted into useful work.

We must, therefore, examine more closely into the nature, composition, and specific properties of the gas employed.

The object of this chapter is to determine—

1. What coal gas is;
2. How much air is required to burn it;
3. How much heat is given out during combustion, and carried away by the residual gases.

As the nomenclature adopted by chemists renders the treatment of the problem of combustion of gases very simple, it will be convenient to begin with a brief explanation of its main principles.

Atoms and Molecules.—All apparently homogeneous substances are composed of extremely small particles, called *molecules*, which, for any given substance, have the same weight.

These molecules, which are the smallest particles of the substance which can exist in the free state, are, in general, composed of still smaller particles, called *atoms*. If all the atoms in the molecules are identical, the substance is known as an *element*, inasmuch as in this case, it is not possible to break it up into two or more distinct bodies. If, on the other hand, two or more different kinds of atoms exist in the molecules, it is known as a *compound*.

The fundamental law upon which chemistry at the present day is based, first enunciated by Avogadro, is—"Equal volumes of gases (under the same conditions of temperature and pressure) contain equal numbers of molecules."

There is another way of stating this, which is sometimes useful. Take a cubic foot of any gas, say oxygen, at a fixed temperature and under a fixed pressure. It contains n molecules, where n is a very large number, only roughly known, and the exact value of which is not required here. The *average space* occupied by a molecule of oxygen then is $\frac{1}{n}$ cubic feet. This is called the "molecular volume" of oxygen. Now, since the same volume of any other gas, say hydrogen, by the law first enunciated, also contains n molecules, its molecular volume is also $\frac{1}{n}$ cubic feet. Hence, another way of stating Avogadro's law is—"All gases have the same molecular volume."

To resume then—

1. All atoms of the same element have the same weight.
2. All molecules of the same compound have the same weight and the same volume.

Chemical Symbols.—As an abbreviation for one atom of an element, the first letter or first two letters of the word is used; thus, C stands for an atom of carbon, H for an atom of hydrogen, O for an atom of oxygen, N for nitrogen, S for sulphur, and so on. Two letters placed together represent a molecule of a compound; thus, CO denotes one molecule of the compound carbonic oxide (carbon monoxide), formed by the combination of one atom of carbon C and one atom of oxygen O. Similarly, CO_2 denotes a molecule of the compound carbonic acid (carbon dioxide), containing three atoms, one of carbon and two of oxygen. $2CO_2$ denotes *two* molecules of carbon dioxide.

Atomic Weights.—Now, the *actual* weights of the atoms are excessively minute, and cannot, with our present means, be determined. But the *relative* magnitude of the weights of the atoms of the various elements can be, and has been, determined with very considerable accuracy. It is customary to take the weight of one atom of hydrogen as unity; and the values for "atomic weight" found in works on chemistry, represent the weights of the atoms of the various elements relative to it.

All the gaseous *elements* dealt with here contain two atoms in each molecule. Thus, H_2, N_2, O_2 are the molecular formulæ for the elementary gases—hydrogen, nitrogen, oxygen, respectively. From this, and with Avogadro's law, it is easy to find the atomic weights of nitrogen and oxygen. It is found that 1 cubic foot of hydrogen weighs ·005591 lb. under standard conditions of pressure and temperature, 1 cubic foot of oxygen weighs ·089456 lb., and of nitrogen, under the same conditions, ·07828 lb. These numbers are in the ratio of 1 : 16 : 14. Hence, if $nH_2 = 1$ unit of weight, by Avogadro's law the same number $nO_2 = 16$

units of weight, and $nN_2 = 14$ units of weight—*i.e.*, the atomic weights of hydrogen, oxygen, and nitrogen are as 1 : 16 : 14. The only atomic weights required in this chapter for gas engines are :—

TABLE OF ATOMIC WEIGHTS.

Element.	Hydrogen.	Oxygen.	Nitrogen.	Carbon.	Sulphur.
Symbol, . . .	H	O	N	C	S
Weight of atom (in round numbers), .	1	16	14	12	32

Molecular Weights.—The "molecular weight"—*i.e.*, the total weight of each molecule, when the hydrogen *atom* is the unit of weight—is obtained by simply adding together the weights of its constituent atoms. Thus the molecular weight of hydrogen, H_2, is 2; of oxygen, O_2, is 32; of carbon monoxide, CO, $12 + 16 = 28$; of marsh gas, CH_4, $12 + (1 \times 4) = 16$. Hence, the weight of 1 cubic foot of hydrogen being ·00559 lb., that of a cubic foot of carbon monoxide is $\left(\frac{16 + 12}{2}\right) = 14 \times \cdot 00559$; of marsh gas, $\left(\frac{4 + 12}{2}\right) = 8 \times \cdot 00559$; and so on for any other gas. The weight of a cubic foot of any gas is thus determined directly its formula is known.

Specific Heat.—If a quantity of heat is added to a gas it may result in an increase of pressure, temperature, or volume, or in an increase of all three. Thus, there may be several "specific heats." The only two generally used are :—

(1) The specific heat at constant volume, which is defined as the number of units of heat required to raise the temperature of the unit weight of gas through 1°, the volume of the gas remaining constant; and

(2) The specific heat at constant pressure, where the gas is allowed to do work by expanding.

Of these the former, which is obviously the smaller number, is sometimes termed the "true specific heat," all the heat going in this case to increase the internal energy of the gas.

For the elementary gases, hydrogen, oxygen, and nitrogen, and also for carbonic oxide, it is found that the amount of heat required to raise equal volumes through 1° is very nearly the same; or, in other words, that the specific heat × molecular weight = constant. It is also found that the specific heats are nearly independent of the temperature, tending only to increase very slightly with it. For the more complicated molecules, such as marsh gas, CH_4, ethylene, C_2H_4, &c., which occur in coal gas, neither of these relations hold, the amount of heat required to raise,

say, 1 cubic foot of ethylene through 1° F. is sensibly different from that required to raise the same volume of air through 1° F., and, further, the specific heat increases more rapidly with the temperature.

The table of specific heats will be found on p. 273.

Chemical Equations.—Chemical equations are symbolic representations of chemical changes. It will be convenient to take one equation as a type, and explain it in detail. The following is a useful example:—

CH₄	+	2O₂	=	CO₂	+	2H₂O
(12 + 4)	+	2 (32)	=	(12 + 32)	+	2 (2 + 16)
Methane.		Oxygen.		Carbon Dioxide.		Steam.

This is interpreted as follows:—Since 1 *molecule* of methane combines with 2 *molecules* of oxygen, it follows, by Avogadro's law, that 1 *volume* of methane combines with 2 *volumes* of oxygen, giving 1 *volume* of carbon dioxide and 2 *volumes* of steam. This same equation also expresses the fact that 16 lbs. of methane require 64 lbs. of oxygen for complete combustion, and give, as the resulting products, 44 lbs. of carbon dioxide and 36 lbs. of steam. By the term "complete combustion" is meant that the hydrocarbon combines with the maximum possible amount of oxygen, giving carbon dioxide and water only as the final products.

When the quantity of oxygen required for the combustion of each constituent is known, the next step is to determine the heat evolved by combustion. As this heat cannot be measured in the cylinder of an engine, the calorimetric value of the gas is obtained by burning it in oxygen. For this purpose an instrument is employed, called a calorimeter. MM. Favre and Silbermann were the first to design an apparatus for testing the heating values of solid, liquid, and gaseous fuels, and other calorimeters capable of greater precision have since been brought out.

Heating Value of Gas.—The amounts of heat developed by the complete combustion of the various carbon compounds contained in coal gas, have been experimentally determined in two ways. Firstly, by burning a current of the gas in question in oxygen or air at the ordinary atmospheric pressure; and, secondly, by exploding a mixture of the two gases in a strong steel "bomb."

The advantages of the second method, which was first used by Andrews, and has been recently employed in an improved form by M. Berthelot and M. Mahler, are that the combustion takes place at constant volume, and that, on account of the much shorter time occupied by the reaction, the "corrections for cooling" of the calorimeter are very much reduced.

The Berthelot-Mahler bomb calorimeter is now largely used for solid, and often for liquid fuels, and gives excellent results, particularly when

the bomb is gilt inside, instead of having an enamel lining. It is not, however, suitable for gaseous fuels, for which the Junkers calorimeter has been specially designed, and is now chiefly employed, both in England and abroad.

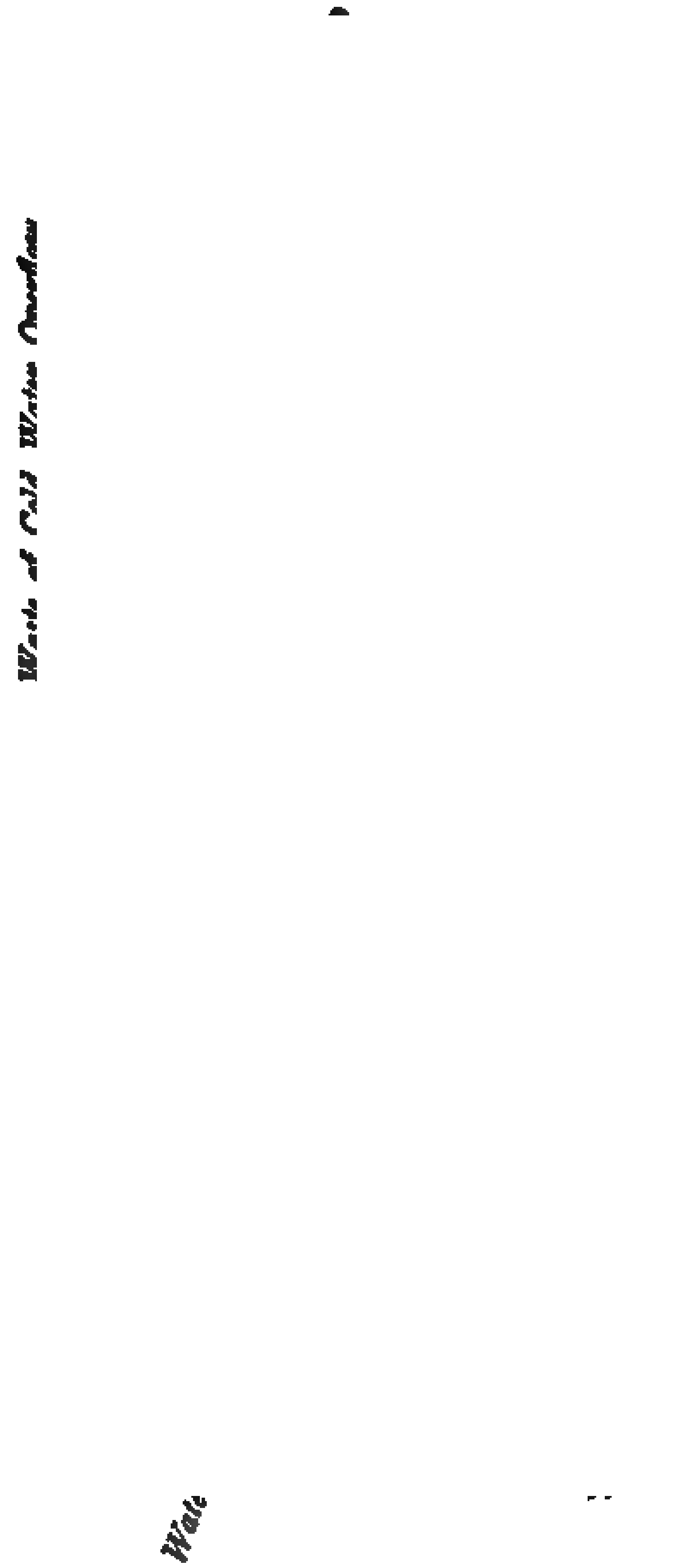

Fig. 118.—Junkers Gas Calorimeter. Sectional Elevation. 1899.

Junkers Calorimeter.—This interesting and important instrument, designed and made by Junkers, of Dessau, is almost exclusively used for measuring the heating value of gases. Up to the present, it is the best calorimeter produced for this purpose; it works well, and is very simple to manipulate. It is based on the principle of the rise in temperature of

Fig. 120.—Junkers Gas Calorimeter, with Gas Meter, &c.

a current of water passing round a jet of burning gas, the heating value of which it is desired to ascertain. The apparatus is shown in vertical and horizontal section in Figs. 118 and 119, and an external general view of the whole at Fig. 120.

It consists of a vertical cylindrical vessel of 4·7 square feet heating surface, with a gas burner alight in the centre, connected to a small but

very accurate gas meter *g* (Fig. 120). A Bunsen burner is used for town gas, or for other gases of high heating value, an ordinary metal tube for poorer gases, or those having a lower heating value. The size of the flame is regulated in inverse proportion to the quality of the gas. The central nozzle *a* (Fig. 120) is connected to any water supply; *b* is an overflow pipe, the discharge from which should be visible, but need not be measured, as this water does not form part of the quantity heated. The cold water from *a* enters the calorimeter at the bottom, through the regulating cock *e*, and passes out after being heated at the top at *c*. The temperatures of this water, in and out, are taken by very accurate thermometers, seen in Fig. 120. A third delicate thermometer gives the temperature of the products of combustion from the gas jet, and a fourth that of the gas in the meter *g*. The water produced by combustion (pipe 35, Fig. 119) runs into the small glass vessel *d* (Fig. 120). This water of condensation plays an important part in determining the "higher" or "lower" heating value of the gas, and it is therefore necessary to measure it carefully. It is produced by the combination of the hydrogen in the burning jet with the oxygen of the air, to form steam. In the calorimeter the latter is condensed, and gives up its latent heat. At *f* is a cock which should be turned on for a few seconds before beginning a test, to allow water and air to come out, so that no air may remain in the pipes. To diminish radiation, the calorimeter is surrounded by a jacket of air.

To make a calorimetric determination of a gas, water is first run from *a* into the outer cylinder of the instrument, outside the vertical smoke tubes, until it escapes at the top at *c*. The gas is then turned on and lighted at the burner, and the jet introduced into the calorimeter, as seen at Fig. 118. The size of the flame, or the quantity of gas passing to it, is carefully adjusted by the cock 22 (Fig. 118) in accordance with the capacity of the calorimeter for absorbing heat, and kind of gas burnt. Air to feed the gas jet enters at the bottom of the vessel, as shown by the arrows (Fig. 118). The products of combustion ascend, and then pass downwards through 48 copper tubes, each $\frac{9}{32}$ inch internal diameter and $11\frac{1}{2}$ inches long (No. 30, Fig. 119) and go to waste at 30 (Fig. 118). The circulating water travels vertically upwards, the hot gases descending in the contrary direction. The quantity of cold water is regulated by cock *e*, and the heated water measured in the cylindrical graduated glass vessel shown to the right in Fig. 120. By varying the quantity of water passing to *e*, before beginning an experiment, the difference in temperature is approximately determined between the water at the outlet and inlet (in ordinary cases a difference of 10° to 20° C. is preferable). This constitutes the main principle of the instrument, which consists in regulating the position of the cock *e* in such a way that the quantity

of circulating water admitted should absorb all the heat given out by the burning gas, so that the products of combustion are discharged practically at atmospheric temperature. The heating surface is sufficient for this purpose, if all is properly adjusted, and the cocks for water and gas carefully manipulated. For oils a special burner is used.

The lbs. of water per minute, its rise in temperature while passing through the calorimeter, and the cubic feet of gas burnt per minute being known, the heating value of the gas in T.U. per cubic foot is calculated by the following formula:—

$$H = \frac{W\,T}{G},$$

in which H is the heating value, W the lbs. of circulating water as measured, T the rise in temperature of the circulating water in degrees F., and G the cubic feet of gas at the temperature and pressure of the room. In other words, the heating value of the gas (in T.U. per lb.) multiplied by the cubic feet of gas burnt, is equal to the weight of circulating water multiplied by its rise in temperature.

Numerical Example.—

$$\text{Let } W = 6{\cdot}65 \text{ lbs. per minute,}$$
$$T = 32{\cdot}5 \text{ degrees F.,}$$
$$G = 0{\cdot}353 \text{ cubic feet; then}$$

$$H\,(x) = \frac{6{\cdot}65 \text{ lbs.} \times 32^{\circ}\text{ F.}}{0{\cdot}353 \text{ cubic foot}} = 612 \text{ T.U. per cubic foot.}$$

Higher and Lower Heating Value.—A difference of opinion prevails in France and Germany upon the definition of the term "heating value of a gas," and whether in a calorimeter the latent heat of the water formed by combustion should be taken, in calculating the heat given to a gas engine. The heating value of a gas is generally determined in a Junkers calorimeter, in which combustion and cooling of the products are carried out at atmospheric pressure. The initial temperature of the charge and the final temperature of the gases of combustion are usually calculated at 18° C., equal to 64° F. All the water produced by combustion in the calorimeter is condensed, except the small portion absorbed by the burnt products, which, if any excess of water is present, are thoroughly saturated when discharged. If the gas and air forming the charge are dry when admitted, all the moisture required to saturate the products must come from the water produced by combustion, and about 1 per cent. of the total heat of the cycle will be withdrawn for this purpose. But if the gas and air are not dry, the moisture they contain will be sufficient to saturate the products. In this, the usual case in practice, the water produced by combustion is condensed, and sometimes even part of the moisture in the gas and air entering the calorimeter, so that the exhaust products are drier than the initial charge.

The heat given to the calorimeter during complete combustion at atmospheric pressure and 64° F., all the water produced by combustion and the steam formed being condensed, is known as the "higher heating value." The "lower heating value" signifies the same quantity of heat generated under the same conditions, but the water produced by combustion in the calorimeter is assumed to be present as superheated steam—that is, as a gas, and not condensed, and the heat is latent. To gasify this water 600 calories per kilogramme, or 1,080 B.T.U. per lb., are required, and therefore the "lower heating value" is obtained by deducting this quantity of heat from the "higher heating value" for every lb. of water produced by the combustion of 1 lb. of gas.

In Germany, England, America, and other countries, the *lower* heating value is always used in calculating the heat efficiency of a gas engine, because it is assumed that all the water vapour generated during combustion is converted into steam when leaving the engine. Therefore its corresponding heat of condensation will be latent and not sensible, and cannot be reckoned as heat given to the cycle. In France the *higher* heating value is taken as the basis of calculation, especially by Professor Witz, who maintains that it is a defect in gas engines that this latent heat of condensation of the water vapour cannot be utilised to produce work, as in a steam engine. As the lower heating value of lighting gas is sometimes 10 per cent. less than the higher, if this latent heat—namely, that absorbed to gasify the water—is left out of account, the efficiency of the gas engine will be increased by about 10 per cent.

In all experiments in which the heat efficiency of an engine is calculated, it should always be stated which of these two values has been taken. Thus the heating value of the oil used in the trial of the Diesel motor at Augsburg was 10,935 calories per kilo., equal to 19,683 B.T.U. per lb., including the latent heat set free in the calorimeter by condensation, and 18,271 B.T.U. per lb., excluding the latent heat. In this case 3·7 grammes of water were formed per kilo. of oil burnt; difference between the two heating values, 7·8 per cent. In the Cambridge oil engine trials the heating value of the oil, not deducting the latent heat of the water condensed, was 19,899 B.T.U. per lb. Corrected for the latent heat absorbed to convert this water into steam, the value was 18,563 B.T.U. per lb.; difference 7·4 per cent. The latter was the value taken during the trials. In the tests on Dowson gas at the Bâle Water Works by Professor Meyer, the calorific value of the gas used was 1,202 calories per cubic metre, equal to 134·62 B.T.U. per cubic foot, the water vapour being taken as wholly converted into steam in the cylinder, and 144 B.T.U. per cubic foot, not deducting the latent heat of the steam; difference 5·2 per cent. The heat efficiency in the French experiments is always lower than that calculated in other countries.

The following table (from Geitel's *Das Wassergas und seine Verwendung in der Technik*) shows the heat of combustion of different gases under these two conditions:—

TABLE OF HEATING VALUE OF GASES.

Gas.	Per Cubic Metre.		Per Cubic Foot.		Per Kilogramme.		Per Lb.	
	Liquefied Water.	Gaseous Vapour.	Liquefied Water.	Gaseous Vapour.	Liquefied Water.	Gaseous Vapour.	Liquefied Water.	Gaseous Vapour.
	Calories.	Calories.	B.T.U.	B.T.U.	Calories.	Calories.	B.T.U.	B.T.U.
Lighting, . .	5,810	5,154	650	577	11,350	10,070	20,430	18,126
Power, . .	1,048	1,048	117	117	838	838	1,508	1,508
Water, . .	3,054	2,813	332	315	4,558	4,199	8,204	7,558

Professor Witz considers the higher as the only real heating value of the gas, and that German scientific experts make an error in calculating from the lower heating value. The available heat of a unit weight of petroleum (or of a cubic foot of any gas) must, he says, include that of the condensed water vapour—*i.e.*, this latent heat must be credited to the cycle, because if the temperature of the gases could be sufficiently reduced by expansion, this heat would be available for work. He assumes that all the steam or water formed by combustion in a calorimeter is condensed in the apparatus, and therefore its latent heat should be included in the heat value of the gas or oil tested, and not deducted according to the German method.

Against this view Professor Meyer protests. It is true, he says, that during the process of combustion in a calorimeter, the heat in the water of condensation is present, nevertheless it should not be credited to the cycle. The exhaust gases escape from a gas-engine cyclinder at a temperature of at least 300° C., and their heat cannot under present conditions be utilised. If under the name "quantity of heat given to the cycle," we understand, as in a steam engine, all the heat available for work above the temperature of the atmosphere, without taking into account how much or how little it can do, and whether it can be completely utilised technically or not, the higher heating value should be taken. All this heat cannot, however, be converted into work on the piston. There may be a difference of 16 per cent. between the higher and the lower heating value, according to the gas used, but one gas does not give 16 per cent. more indicated work than another. The theoretical heat efficiency of any engine can never be equal to unity, because all the heat in the working agent below the normal temperature down to absolute zero cannot be utilised. Further, the exhaust gases in an engine cylinder are largely mixed with inert gases, and therefore the water will be condensed at a temperature much below 100° C. It is desirable, says

Professor Meyer, to take the lower heating value as heat added to the cycle, in calculating the thermal efficiency, and determining the temperature of combustion. It enables us to judge correctly of the efficiency of different engines fed with gases yielding more or less water when tested in a calorimeter. In other words, if the higher heating value be taken as the basis of the thermal efficiency, the engine is tested not only by its capacity for converting the heat supplied to it into work, but also by the amount of water the gas with which it is fed contains, since the more water in the gas, the more latent heat will be liberated by its condensation.

Professors Kennedy and Burstall follow the German method, and subtract the latent heat of the H_2O. No internal combustion motor can, in Professor Burstall's opinion, be imagined which rejects heat at a temperature below 212° F. Otherwise a condenser must be used, and hitherto such a method of returning heat to a gas or oil engine has not been found practicable. If owing to its mixture with neutral gases steam is actually discharged from the cylinder at a lower temperature, it cannot be supposed to do work. For gas engine practice Professor Burstall thinks it "better to use a value that is in accordance with the actual conditions of the engine," although of course it is theoretically possible to cool down the products to, say, 16° C. = 60° F. All the leading authorities in England and America endorse these views.

The author was also of opinion that it is the lower and not the higher heating value which ought to be taken as a basis for calculating the heat efficiency. In the abstract, and on purely theoretical grounds, Professor Witz is right in maintaining the desirability of the higher heating value. If gas engines conformed to this ideal type, and it were possible to expand the gases in them to atmospheric pressure, and utilise completely the heat they contain, this heating value would correctly represent the quantity of heat given to the cycle. But at present such a heat efficiency is impossible to realise. The temperature at which the exhaust gases leave the cylinder is far too high to allow of any condensation of the escaping steam, and therefore the latent heat it contains can never become sensible, and be available for work. A gas calorimeter measures the heat in any gas or oil burnt in it, and we have to compare the heat thus set free with that of the same gas or oil when utilised in the cylinder of an engine for power. No water is or can be condensed, and, therefore, its latent heat should be excluded from the calorimetric value. This was the opinion of the Cambridge experts, who during the oil engine trials in 1894 took the heating value of the oil with the water uncondensed.

With the help of a calorimeter, the heat of combustion of coal and other fuels, solid and liquid, and of most kinds of combustibles, has been

determined. The following table gives the values, by different authorities, of the heat produced by the combustion of the chemical constituents of coal gas, and also of solid carbon :—

HEAT PRODUCED BY THE COMBUSTION OF H, C, CO, &c. (from Ostwald's *Verwandtschafts-Lehre*, 1887).

Unit Weight or Gramme of the following Gases and Carbon.	Units of Heat evolved by Complete Combustion of 1 gramme at 17° C., and Atm. Pressure.		
	Favre and Silbermann.	Thomsen.	Berthelot.
	Calories.	Calories.	Calories.
Hydrogen, H,	34,460	34,180	34,600
Carbon, C,	8,080	8,080	8,138
Carbon monoxide, CO,	2,403	2,429	2,439
Marsh gas, CH_4,	13,062	13,244	13,344
Ethylene, C_2H_4,	11,857	11,907	12,193
Benzene, C_6H_6,	9,915	10,249	9,949

That is to say, 1 gramme of carbon completely burnt gives out sufficient heat to raise 1° C. the temperature of 8,080 grammes of water from and at 17° C., or 1 gramme water 8,080° C. according to Favre and Silbermann's reckoning. MM. Berthelot and Mahler claim to have obtained more accurate results with their calorimeters, owing to the more rapid and complete method of combustion; their values are slightly higher. The following table shows the number of British thermal units given out by the complete combustion of 1 cubic foot of each of the gases usually present in coal gas :—

TABLE OF B.T.U. RESULTING FROM THE COMPLETE COMBUSTION OF 1 CUBIC FOOT OF DIFFERENT GASES.

Name of Gas.	Calorific Values per Cubic Foot (measured at 32° F. and 30 ins. pressure of Mercury) in B.T.U. (British Thermal Units).
Hydrogen,	293·5
Carbon monoxide,	342·3
Methane,	1,066
Ethylene,	1,678
Propylene,	2,479
Butylene,	3,275
Benzene,	4,023

(To be quite accurate, these values must be multiplied by a factor obtained from the temperature and barometer height at the time of experiment.)

The unit of heat used here is the amount of heat required to raise 1 lb. of water, at 64° to 68° F., 1° F. The difference between the specific heats of water at 0° C. and water at 19° is only about 1 in 1,000. The products are supposed to be cooled down to about 19° C. As the figure given for hydrogen includes the latent heat of steam, it may be replaced by the figure 52,500,* in which this latent heat remains in the gas.

Composition of Coal Gas.—As regards the actual composition of coal gas, the following table, taken from Schöttler, shows an average composition of 1 cubic foot of ordinary Hanover lighting gas, distilled from coal in retorts, without admixture of air:—

TABLE SHOWING AVERAGE COMPOSITION OF 1 CUBIC FOOT OF HANOVER COAL GAS (*Schöttler*).

Volume.	Name of Gas.	Chemical Symbol.
Cubic Feet.		
·0069	Benzene.	C_6H_6
·0037	Butylene.	C_4H_8
·0211	Ethylene.	C_2H_4
·3755	Methane.	CH_4
·4627	Hydrogen.	H_2
·1119	Carbon monoxide.	CO
·0081	Carbon dioxide.	CO_2
·0101	Nitrogen.	N_2
1·0000		

The first three gases are called "heavy hydrocarbons," and as they are all frequently absorbed together by the same reagent (fuming sulphuric acid), they are generally included together under one head.

Benzene, C_6H_6, burns with excess of oxygen as follows:—

Molecular weight, 78; weight of 1 cubic foot = 39 × ·005591 = ·2181 lb.

$$\dagger\, C_6H_6 + 7\tfrac{1}{2}O_2 = 6CO_2 + 3H_2O$$
$$(1 \text{ vol.}) + (7\tfrac{1}{2} \text{ vols.}) = (6 \text{ vols.}) + (3 \text{ vols.})$$

Butylene, C_4H_8 (Synonym—Tetrylene).

$$C_4H_8 + CO_2 = 4CO_2 + 4H_2O$$
$$(1 \text{ vol.}) + (6 \text{ vols.}) = (4 \text{ vols.}) + (4 \text{ vols.})$$

Molecular weight, 56; weight of a cubic foot, 28 × ·005591 = ·1566 lb.

* 52,500 B.T.U. in 1 lb. H., ∴ 52,500 × 0·00559 (weight 1 cubic foot H per lb.) = 293·5.

† To be strictly accurate, the equation should be doubled, but the volume relations are more clearly shown as they are. Of course, half a molecule is a physical impossibility.

Ethylene, C_2H_4 (Synonym—Olefiant gas, ethene).

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$$
$$(1 \text{ vol.}) + (3 \text{ vols.}) = (2 \text{ vols.}) + (2 \text{ vols.})$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Methane, CH_4 (Synonyms—Marsh gas, firedamp).

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$
$$(1 \text{ vol.}) + (2 \text{ vols.}) = (1 \text{ vol.}) + (2 \text{ vols.})$$

Molecular weight, 16; weight of a cubic foot, 8 × ·005591 = ·044728 lb.

Hydrogen, H_2.

$$^*H_2 + \tfrac{1}{2}O_2 = H_2O$$
$$(1 \text{ vol.}) + (\tfrac{1}{2} \text{ vol.}) = (1 \text{ vol.})$$

Molecular weight, 2; weight of a cubic foot, ·005591 lb.

Carbon Monoxide, CO (Synonym—Carbonic oxide).

$$^*CO + \tfrac{1}{2}O_2 = CO_2$$
$$(1 \text{ vol.}) + (\tfrac{1}{2} \text{ vol.}) = (1 \text{ vol.})$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Carbon Dioxide, CO_2 (Synonym—Carbonic anhydride).

Molecular weight, 44; weight of a cubic foot, 22 × ·005591 = ·123 lb.

Nitrogen, N_2, does not play any active part in the combustion, but remains unchanged throughout the whole set of operations. It acts as a mere diluent.

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Since the whole of the oxygen represented in the above equations has to come from the air, and since there are in the air 79 volumes of nitrogen to 21 of oxygen, it follows that one volume of oxygen must be replaced by about 4·762 of air.

The preceding data may be conveniently tabulated as follows:—

TABLE SHOWING PRODUCTS OF COMBUSTION OF THE VARIOUS CONSTITUENTS OF COAL GAS.

Name.	Formula.	Density in lbs. per cub. ft. at 0° C. and 760 mm. pressure.	Volumes Oxygen required for Complete Combustion.	Volumes of Air.	Volumes CO_2 Produced.
Benzene, . . .	C_6H_6	·2181	7½	35·71	6
Butylene, . . .	C_4H_8	·1566	6	28·57	4
Ethylene, . . .	C_2H_4	·0783	3	14·28	2
Methane, . . .	CH_4	·0447	2	9·52	1
Hydrogen, . .	H_2	·00559	½	2·38	0
Carbon monoxide, .	CO	·0783	½	2·38	1
Carbon dioxide, .	CO_2	·1230	...	...	...
Nitrogen, . . .	N_2	·0783	...	...	...

* To be strictly accurate, these equations should be doubled, but the volume relations are more clearly shown as they are. Of course, half a molecule is a physical impossibility.

COMPOSITION OF COAL GAS IN VARIOUS CITIES AND TOWNS,

IN PERCENTAGE BY VOLUME.

Constituents in Gas, Percentage by Volume.	London Gas-Light and Coke Co.	London Society of Arts' Trial.	Manchester.	Kilmarnock Trial, Prof. Kennedy.	Gas-Motoren Fabrik Cologne (Slaby).	Bonn (Clerk).	Dresden (Schöttler).	Hanover (Schöttler).	Hoboken, New-York (Brooks & Steward).	Paris (Peclet).	Paris (Witz).
Heavy hydro-carbons, . . .	4·41	3·77	6·46	5·55	3·50	4·75	3·00	3·17	6·60	5·80	5·50
Marsh gas, CH_4,	37·64	37·34	34·90	42·80	34·40	43·12	33·40	37·55	37·30	33·10	32·30
Hydrogen, H, .	47·99	50·44	45·58	43·60	56·90	39·80	48·70	46·27	39·50	50·10	52·80
Carbon monoxide, CO, ...	3·75	3·96	6·64	4·30	5·20	4·66	8·00	11·19	4·30	6·30	5·60
Carbon dioxide, CO_2, ...	...	0·51	3·67		...	3·02	1·50	0·81	2·70 and impurities.	1·50	...
Oxygen, O, . .	0·26	...	... H_2S 0·29	1·05	...	...	1·40	...	1·40	0·50	...
Nitrogen, N, . .	5·95	3·98	2·46	2·70	...	4·65	4·00	1·01	8·20	2·70	3·80
Totals, . .	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

The composition of lighting gas is not constant. It depends upon the quality of the coal, the temperature of the retort, and the period of distillation. The following table, from experiments by Dr. Wright,* shows the influence of the time that has elapsed after charging the retorts :—

COAL GAS.

Constituents.		Time after Commencement of Distillation.		
		10 minutes.	3 hours 25 mins.	5 hours 35 mins.
		Per cent.	Per cent.	Per cent.
Hydrogen, ...	H_2	·2010	·5268	·6712
Marsh gas, . . .	CH_4	·5738	·3354	·2258
Carbon monoxide, . .	CO	·0619	·0621	·0612
Heavy hydrocarbons, .	...	·1062	·0304	·0179
Nitrogen, ...	N_2	·0220	·0255	·0078
Carbon dioxide, . . .	CO_2	·0221	·0149	·0150
Sulphuretted hydrogen, .	SH_2	·0130	·0049	·0011
Cubic foot,		1·0000	1·0000	1·0000

The table on p. 298 shows the composition of the coal gas in most of the large towns of Europe, &c.

Calorific Value of 1 Cubic Foot of any Coal Gas.—From the table of B.T.U., p. 295, it is now easy to find the calorific value of 1 cubic foot of any lighting gas, it being only necessary to multiply the volume percentage of each combustible gas by its calorific power per cubic foot, as given in the second column of that table.

Take for example the following gas :—

Name of Gas.	Volumes in cub. ft.	Calorific Value B.T.U. in 1 cub. ft.	Weight in lbs. per cub. ft.	Volumes Oxygen required.
Methane, ...	·4280	456·2	·019130	·8560
Ethylene, ...	·0277	46·5	·002169	·0831
Butylene, ...	·0278	91·0	·004353	·1668
Hydrogen, ...	·4360	128·0	·002437	·2180
Carbon monoxide, . . .	·0430	14·7	·003366	·0215
Nitrogen, CO_2 and O_2, . .	·0375	...	·003220	...
	1·0000	736·4	·034680	1·3454

i.e., 1 cubic foot of this gas on complete combustion would yield 736·4 B.T.U., or $\frac{736{\cdot}4}{{\cdot}03468} = 21{,}230$ B.T.U. per lb. of gas, and would require 1·345 volumes of oxygen or 6·407 of air for complete combustion.

* *Journ. Chem. Soc.*, No. 261, 1884.

As a matter of fact, when 1 cubic foot of this gas is mixed with 1·345 volumes of oxygen, the explosion is so violent as to be quite unmanageable. Even when diluted with nitrogen as in air, the correct proportions for complete combustion (here 6·407 volumes of air to 1 of coal gas) still give too violent an explosion. This can be moderated by using an excess of air which acts as a diluent, lowering the partial pressure of the re-acting gases. This excess of air, together with the whole of the 5·062 volumes of nitrogen introduced with the re-acting oxygen, and the nitrogen originally present in the gas, unavoidably impairs the efficiency, as the whole of this has to be heated up to the temperature of the cylinder gases. Further, it is discharged at a high temperature (about 400° to 450° C.) together with the carbon dioxide produced in the reaction, and the whole of this heat is wasted. In the various producer and water gases, formed by forcing air or mixtures of air and steam over red-hot coal, the amount of nitrogen is considerable, and accordingly much less air is required for their complete combustion. Thus, wherever coal gas requires from 6 to 15 volumes of air, Dowson gas requires only 1½ volumes.

The following table gives the composition of several of these cheaper gases :—

Table of Composition of Power Gases in Volume Per Cent.

Name of Gas.	Oxygen, O.	Hydrogen, H.	Marsh Gas, CH_4, and Olefiant Gas.	Carbon Monoxide, CO.	Carbon Dioxide, CO_2.	Nitrogen, N.
Producer (Siemens'),	...	8·60	2·40	24·40	5·20	59·40
Water,	...	51·89	0·10	40·08	4·80	3·13
Water (Essen),	...	48·60	0·40	44·00	3·30	3·70
Carburetted water,	0·21	39·40	25·11	29·03	...	6·29
Natural,	...	22·00	73·00	0·60	0·60	3·00
Tessié du Motay,	...	43·25	1·25	46·50	5·00	4·00
Wilson,	...	15·00	1·40	25·90	3·70	54·00
Strong,	...	53·00	...	35·00	4·00	8·00
Lowe,	...	30·00	...	28·00	34·00	8·00
Dowson,	0·03	18·73	0·62	25·07	6·57	48·08
Dowson,	0·23	24·36	1·31	17·55	6·07	50·48
Lencauchez,	0·50	20·00	4·00	21·00	5·00	49·50
Taylor,	...	12·00	1·20	27·00	2·50	57·30
Mond,	...	29·00	2·00	11·00	16·00	42·00
Riché (wood gas),	...	44·20	12·40	22·00	21·30	...

See Diagram of Combustible Gases, p. 200.

It may be useful, as an example, to work out the calorific value of one of these, say Siemens' producer gas :—

HEATING VALUE OF 1 CUBIC FOOT OF SIEMENS' PRODUCER GAS IN BRITISH THERMAL UNITS.

Gas.	Symbol.	Amount in 1 cub. ft.	Calorific Value per cub. ft.	Calorific Value per cub. ft. of Gas in B.T.U.	Volumes of Oxygen required in cub. ft.	Volumes of Air required in cub. ft.
Hydrogen, . . .	H_2	·086	293·5	25·24	·043	·205
Methane, ...	CH_4	·024	1066·0	26·58	·048	·229
Carbon monoxide, .	CO	·244	3423·0	83·51	·122	·581
Carbon dioxide, . .	CO_2	·052	...	...	...	...
Nitrogen, ...	N_2	·594	...	...	...	...
		1·000	...	135·33	0·213	1·015

Hence the calorific power of this producer gas is, roughly speaking, only one-fifth that of an equal volume of coal gas, and it requires only a little more than its own volume of air for complete combustion.

Interesting calculations by A. Naumann on the transformation of heat into chemical energy in the production of power gas will be found in the *Berichte der deutschen chemischen Gesellschaft*, No. 25, 1892. In the formation of producer or air gas, heat is liberated, in that of water gas it is absorbed, and the author considers how the surplus heat of the one process can be utilised in the other. This may be done either by introducing water with the air for combustion (as in Dowson gas), thus forming what he calls "water producer gas," or by introducing CO_2 to form carbon dioxide producer gas.

The same subject has been treated by Mr. Norton Humphreys in a paper on "The Gas Engine, from a theoretical point of view."* Volume for volume, the calorific value of lighting gas increases with its illuminating power. The richer the gas, the greater its specific gravity, but if judged by weight, its quality does not affect the heating value. To estimate the latter accurately, not only the weight, but also the chemical composition of a gas should be known.

The following table is taken from Mr. Dugald Clerk's paper on "Recent Developments in Gas Engines," in the *Proceedings of the Institution of Civil Engineers*, vol. cxxiv., 1895-1896. It is calculated from an analysis by Dr. P. F. Frankland in a paper read before the Society of Chemical Industry, 5th May, 1884, and gives the weight, volume, and heating value of lighting gas in most of the large towns in England and Scotland :—

* *Gas Engineer's Annual*, 1889.

DATA CALCULATED FROM DR. P. F. FRANKLAND'S ANALYSIS OF VARIOUS GASES IN DIFFERENT BRITISH TOWNS.

Town.	Weight of 100 Cubic Feet at 14·7 lbs. Pressure per Square Inch.		Volume of 1 lb. Weight at 14 lbs. per Square Inch Pressure.		Heat evolved by 1 lb. Weight in British Thermal Units.	Heat evolved by 1 Cubic Foot at 14·7 lbs. pressure.				Volume at 17° C. and 14·7 lbs. per Sq. In. Pressure, which evolves Heat equivalent to 1,980,000 foot-lbs., or 1 H.P. for 1 Hour.
	At 0° C.	At 17° C.	At 0° C.	At 17° C.		At 0° C.		At 17° C.		
	Lbs.	Lbs.	Cub. ft.	Cub. ft.		B.T.U.	Foot-lbs.	B.T.U.	Foot-lbs.	
Edinburgh,	4·355	4·100	22·97	24·39	19,827	863	666,560	813	627,740	3·154
Glasgow,	3·926	3·691	25·47	27·09	20,604	810	625,960	762	588,530	3·364
St. Andrews,	4·182	3·937	23·91	25·40	19,600	820	633,030	772	595,890	3·322
Liverpool,	3·908	3·679	25·60	27·18	19,551	764	589,770	720	555,490	3·564
Preston,	3·533	3·326	29·13	30·07	20,471	703	554,268	681	525,720	3·766
Nottingham,	3·435	3·234	29·11	30·92	21,375	734	567,040	691	533,830	3·709
Leeds,	3·932	3·702	25·43	27·01	18,786	739	570,490	695	537,110	3·686
Sheffield,	3·738	3·519	26·76	28·42	20,520	767	592,150	830	557,570	3·551
Birmingham,	3·793	3·571	26·37	28·00	17,645	669	516,730	630	486,650	4·069
Bristol,	3·485	3·281	28·69	30·48	20,945	732	563,750	687	530,640	4·713
London—										
Gaslight and Coke Co.,	3·332	3·137	30·01	31·88	20,666	688	531,770	648	500,580	3·955
S. Metropolitan Co.,	2·866	2·700	34·89	37·04	22,912	664	507,110	618	477,680	4·145
Redhill,	3·160	2·975	31·65	33·61	21,906	692	534,480	652	503,320	3·934
Gloucester,	3·172	2·986	31·54	33·49	22,282	707	545,560	665	513,790	3·853
Newcastle-on-Tyne,	3·053	2·874	32·75	34·79	21,494	656	506,810	618	477,090	4·156
Newcastle-under-Lyne,	3·151	2·966	31·74	33·71	21,548	679	524,250	639	490,361	4·011
Brighton,	2·862	2·694	34·94	37·12	23,432	670	517,890	631	487,480	4·062
Southampton,	2·852	2·431	35·06	41·13	23,369	666	514,730	568	438,760	4·153
Ipswich,	3·500	3·294	28·57	30·36	18,963	665	513,530	572	483,250	4·097
Norwich,	2·880	2·711	34·72	36·89	23,782	685	528,940	645	497,820	3·977

CHAPTER XV.

THE UTILISATION OF HEAT IN A GAS ENGINE.

CONTENTS.—Gas Power *versus* Steam Power—Comparison of Heat Efficiencies of Steam and Gas Engines—Balance of Heat—Four Efficiencies—Ideal Diagram—Actual Otto Diagram—Ayrton and Perry's Experiments—Formulæ of Efficiency—Four Types of Engine—Heat Balance Sheet.

HAVING now considered the laws governing heat, the chemical nature of the changes taking place in the charge of gas and air in an engine cylinder, and the heat developed, we come to the question how far this heat is really usefully employed as motive power. Upon this vital point the whole theory and practice of a heat engine rest. The heat supplied is used to drive out a piston, but it can never all be turned into work. The analyses and calculations of the heat of gases in the preceding chapter enable us to determine how much heat goes into a motor cylinder, and we must now try and trace what becomes of it. What is the proportion wasted and utilised? What are the causes of the waste of heat, and consequently of power, and how far can this loss be avoided, in the construction and working of a heat engine?

An erroneous idea was formerly prevalent that heat is a mysterious attribute imparted to a body, which cannot be measured or accounted for. The heat evolved in a gas by combustion in a cylinder does not disappear in some unknown manner. Either it remains to raise the temperature of the gas, or it is dissipated in one of three different ways. A certain quantity is radiated into the atmosphere through the walls of the cylinder, and into the water jacket. Some is expended in power, according to the law of the mechanical equivalent; and a proportion, varying according to the more or less perfect cycle of the engine, is left at the end of expansion, to be carried off to the atmosphere at the exhaust stroke.

Gas Power as Compared with Steam Power.—It has now been proved by experiment that a good gas engine turns at least double as much heat into work as a good steam engine. This is chiefly because the range of working temperatures is very much higher. In a boiler and steam engine, or what may rightly be called an external combustion motor, the source of heat, the furnace, is separated from the engine, and the steam is raised to its highest temperature before it enters the cylinder. However carefully the steam pipes may be covered, they carry off some heat. The temperature of the working agent cannot be so great

when heat is added externally, before work on the piston is begun, as when it is imparted actually inside the cylinder, as in a gas motor. When the water in a boiler is converted into steam, a change of physical condition takes place. A certain quantity of heat becomes latent, or is stored up without raising the temperature of the steam, in order to produce the change from a liquid to a gaseous state. Nor does steam wholly conform to the law of Gay-Lussac, because it is not a perfect gas. It increases more rapidly in pressure than in temperature, when heat is applied to it. At a temperature of 450° C. absolute, it has a pressure of 10 atmospheres = 150 lbs. to the square inch. From these causes the initial temperature of the steam is relatively low; the range, or difference between the two sources, is never very great, and consequently less heat is available to be utilised in work.

In gas engines the conditions are very different. Combustion takes place in the cylinder itself, or in a contiguous chamber, and there is no boiler or its equivalent, except when the engine is driven with power gas. The gas is introduced into the cylinder at a comparatively low temperature. The heat is produced at once by explosion and combustion, and utilised on the piston. The theoretical temperature of explosion, obtained by calculating the heat of combustion of the chemical constituents of the gas, is estimated at from 2,600° to nearly 4,000° C. To two causes—namely, internal combustion and permanence of physical state in the gas—the greater practical efficiency of a gas engine is chiefly due. It must not, however, always be assumed that, in all cases, the power at the end of the crank shaft is obtained more economically, because the mechanical efficiency of a gas engine, or the ratio of brake to indicated horse-power, is generally lower than that of a steam engine. In other words, a gas engine often takes more power to drive itself than a good steam engine.

It is of much practical importance that the various cast-iron piston rings should, in a gas engine, be made to fit even more tightly than in a steam engine, because the initial pressures in the former are very much higher. The rings should be carefully examined from time to time, to see that no leakage has taken place.

The **Heat Efficiency**, taking the B.H.P., of the best modern mill steam engines, triple-condensing, steam jacketed, using saturated steam of about 160 lbs. pressure, was, a few years ago, from 19 to 14 per cent. This efficiency is yielded by engines of from 750 to 350 I.H.P., as shown in the tables published by the author in *The Engineer*, October 13, 1899. For ordinary compound engines this heat efficiency would be lower, and for the usual single-cylinder engines still less. In the eleven best gas engines using town gas, of Table No. 1, the heat efficiency, taking the B.H.P., varies from 25 to 18 per cent. for motors develop-

ing from 60 to 5 I.H.P. In engines driven with power gas this efficiency works out rather higher. Taking the first eight in Table No. 5, developing from 490 to 51 I.H.P., the heat efficiency per B.H.P. varies from 29 to 20 per cent. In Professor Meyer's excellent trials on an engine driven with blast-furnace gases, indicating 80 H.P., the heat efficiency for the B.H.P. was 25 per cent. In the important trial at Seraing in March, 1900, on the large 600 H.P. engine, a heat efficiency of 26 per cent. per B.H.P. was obtained (see Table No. 7).

But there are limits to the heat produced by internal combustion in a gas engine cylinder. Far more heat is developed than can be utilised, or brought safely into contact with the walls and working parts of the engine. Professor Witz says that the limit of working temperature in a heat engine throughout the stroke is estimated at about 570° absolute = 300° C. It is true that much higher temperatures are obtained in a gas engine; they cannot indeed be avoided, but neither can they at present be utilised. Theoretically of such value, in practice the gain obtained by these high temperatures must be deliberately sacrificed. A temperature of 1,600° C. or 1,873° absolute is taken by the best authorities as an average maximum temperature of explosion, and it is seldom lower than 1,000° C. or 1,273° absolute. Such heat must be instantly counteracted and dispersed, and this is obtained by circulating water in the jacket round the cylinder, and thus lowering the temperature of the gas at explosion and afterwards. If it were not for these practical difficulties, the 25 per cent. actual efficiency mentioned above would be considerably increased. In the formula $\frac{T_1 - T_0}{T_1}$, p. 277, T_1 is the maximum temperature of explosion. Practically about one-third to one-half this heat T_1 is carried off by the action of the walls and water jacket, and much of the remainder escapes with the unburnt gases. The colder walls abstract heat which must be dispersed, but might with great advantage be retained. Their action is necessary, but not perhaps to its full extent, and here is a great opening for future improvement.

Balance of Heat.—A most useful method of studying heat and its utilisation in any engine was first introduced by the late G. A. Hirn. He drew up what he termed a heat balance sheet, showing on one side all the heat given to an engine, and on the other how it was expended. It is now usual, following his method, to make such a heat balance, in calculating the results of an engine test. The heat received is put on one side of the account, and that dissipated, measured, and unaccounted for on the other. In a gas engine such a heat account, as shown by actual experiments, will be found on the next page.

The figures vary much with different engines, but these may be

taken to represent fair working conditions. They are from Professor Capper's trial of a 7 nominal H.P. Crossley engine. (See other Heat Balance Accounts on p. 313.)

The actual heat supplied to an engine cannot be accurately calculated, unless the calorific value of the gas is known. This may be determined either by chemical analysis, or by combustion in a calorimeter (see p. 289). The gas varies from hour to hour in the proportions of its chemical constituents, and its heating value differs in every town. The amount of air used to dilute the charge is also an element of uncertainty in making calculations. The ordinary method is to measure the quantity of gas entering the cylinder by a meter, and to calculate the air consumption from the total volume, but this is an unsatisfactory plan. A certain amount of the products of combustion almost always remain in the cylinder, mixing with the fresh charge, and as the quantity of gas admitted does not vary, they must reduce the proportion of air entering with it. The quantity of air should be actually measured, and this has been done by Dr. Slaby and others. It is not an easy process, but is essential for accurate trials.

GAS ENGINE—HEAT BALANCE ACCOUNT (AVERAGE).

Dr. Heat received by the Engine.		Heat accounted for, &c. *Cr.*	
	Per cent.		Per cent.
Heat units (T.U.) received per explosion, . .	100	In work (T.U.) I.H.P., .	22·32*
		Carried off by jacket, .	32·96
		Carried off in exhaust gases,	43·29
		Carried off by conduction and radiation, and unaccounted for, . .	1·43
Total, . .	100	Total, . .	100

Expansion.—The utilisation of heat in a gas engine, and its transformation into work, is mainly obtained during the two processes of expansion and compression. The uses of compression, and the great advantages derived from it, have already been explained. It reduces the original volume of the gases, and increases their power of expansion. But since the temperature obtained by explosion in a gas engine is high, the expansive force of the gases is correspondingly high, and is never completely utilised. The gases are always discharged into the atmosphere at a considerable pressure, which, had it been possible to prolong the stroke indefinitely, might be turned to useful account in doing work upon the piston. It is on account of this high expansive energy of the gases that most modern writers insist upon ignition at the dead point.

* In large modern gas engines this percentage is now much higher.

The whole heat is added, and explosion takes place as far as possible at constant volume, or before the piston has moved, and thus the whole volume of the cylinder is available for the expansion of the gases.

A series of interesting experiments was made by Herr Staus, to determine the amount of heat or energy carried off in the exhaust gases at discharge, by means of an "exhaust calorimeter" designed by him. It consisted of a vertical vessel in three parts, into the bottom of which the exhaust gases were admitted, and passed into a coil of pipes. Water was sprayed on to the pipes from above, and collected at the bottom, and its rise in temperature, due to the cooling of the gases, measured. One hour's test was made on a 4 H.P. Otto engine, running at 161 revolutions per minute. The consumption of gas of 668 B.T.U. per cubic foot heating value was 30 cubic feet per B.H.P. and 23 cubic feet per I.H.P. hour. Thermal efficiency (or heat converted into indicated work) 16·18 per cent. Heat lost to the cooling jacket 44·44 per cent. lost to exhaust 37·58 per cent., by radiation 1·8 per cent. The rise in temperature of the water in the exhaust calorimeter was 11° C. = 19·8° F.

Efficiencies.—Engineers often employ four kinds of Efficiencies to represent the utilisation of heat and power in an engine.

I. The first is known as the Maximum Theoretical Efficiency of a perfect engine, and is defined in the preceding chapters. It is expressed by the formula $\frac{T_1 - T_0}{T_1}$, and shows the working of a perfect engine between these limits of temperature (T_1 and T_0 absolute).

II. The second is the Actual Heat Efficiency, or the ratio of the heat turned into work to the total heat received by the engine. The work is often given in I.H.P., but B.H.P. should be added if possible, and it is the best standard of comparison. (See Table of trials for many examples.)

III.—The third is the ratio between the second (actual heat efficiency) and the first (maximum theoretical efficiency). It represents the maximum proportion of possible heat utilisation actually obtained by the engine.

IV. The fourth is the Mechanical Efficiency. It is the ratio between the useful horse-power (or brake H.P.) available at the end of the crank shaft, and the total indicated horse-power. The difference between the two is the I.H.P. necessary to drive the engine itself. Suppose an engine indicating a total of 100 H.P., and that by a special experiment it was found that 20 H.P. was required to keep the engine going at the same speed, without any external work. In such a case the mechanical efficiency would be 80 per cent.

Ideal Diagram.—The diagrams representing the area of work in a heat engine are similar to that of Carnot's perfect cycle, but vary in

shape according to the type of motor, and the curves produced by the pressure, expansion, and cooling of the gases. Fig. 121 represents a perfect cycle, in which the gases are compressed before ignition. The line A B is the abscissa, and is proportionate to the cylinder volume and the length of stroke. The line D F is the ordinate of pressure, and the mean height of the area D F B C D gives the mean pressure. Explosion takes place at D, the pressure rising instantly to F without change of volume, as the piston is stationary. From F to B the charge expands, and all the work of the engine is done. The pressure and temperature fall in consequence. From B to A the gases are discharged at atmospheric pressure. The piston draws in the charge from A to B, and compresses it into the clearance space.

In this ideal diagram all the lines follow Carnot's cycle. Compression and explosion are both adiabatic—that is to say, no heat is lost, but all is transformed into energy, and again refunded by compression of the charge. The gases also expand till their pressure falls to atmospheric, and their whole energy is supposed to be utilised. The diagram is formed of two adiabatic lines, compression and expansion; a vertical explosion line with no increase in volume during the rise in pressure, and a horizontal exhaust line, with no back pressure during the return to the original volume.

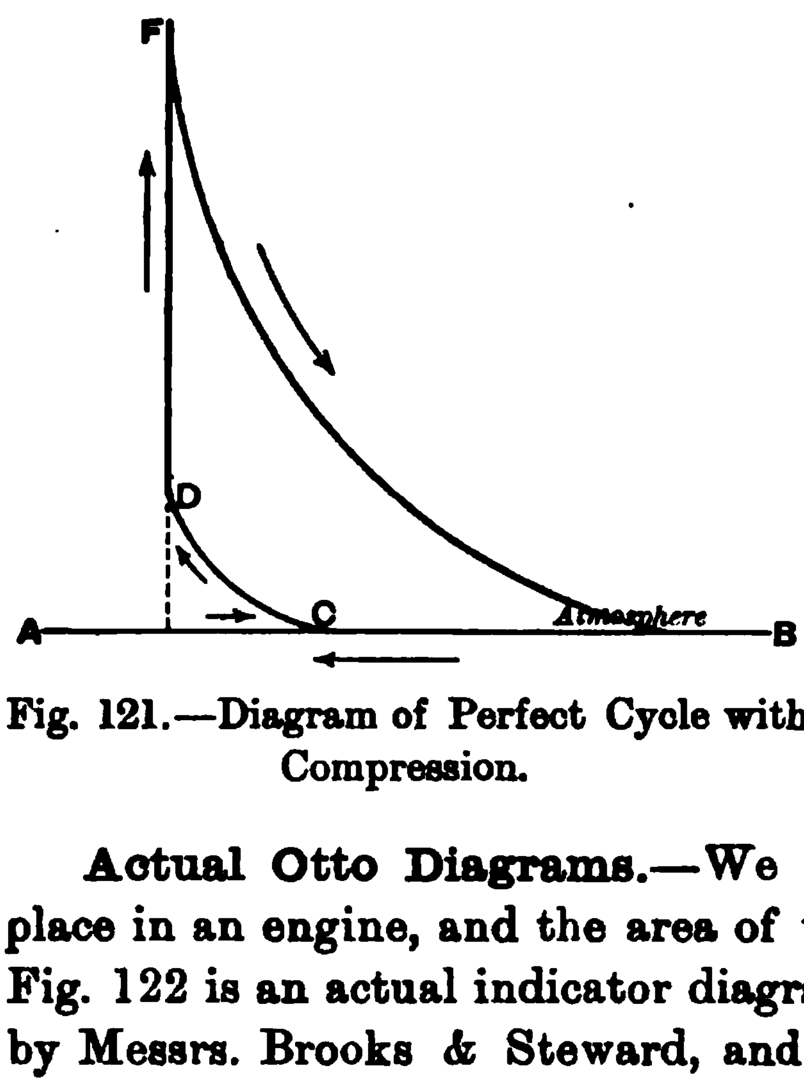

Fig. 121.—Diagram of Perfect Cycle with Compression.

Actual Otto Diagrams.—We will now consider what really takes place in an engine, and the area of work shown by an indicator diagram. Fig. 122 is an actual indicator diagram taken at a trial of an Otto engine by Messrs. Brooks & Steward, and similar to most modern diagrams. Here A B is the line of atmospheric pressure, and almost parallel with it is the line of admission A C. It will be remembered that, in the Otto cycle, the piston draws in the charge during one entire forward stroke. If the lines A B and A C be compared, the latter will be seen to be rather lower, showing that there is a small vacuum in the cylinder, and the charge is admitted at a pressure slightly below that of the atmosphere. From C to D the charge is compressed, the pressure rises, but the line falls below the adiabatic (compare C D in Fig. 121). Evidently the heat is carried off and abstracted by the cooler walls, as well as stored up by the compression of the gas. From D to F is the explosion line, which also deviates from the perfectly vertical line in Fig. 121. The

top of the diagram is rounded, showing that the piston had begun to move a little before explosion was complete; the pressure did not at once attain its maximum, nor was combustion complete when the highest pressure was reached. The line of expansion F G differs from the true theoretical adiabatic curve. Various circumstances, such as "after-combustion," cooling action of the walls, and other causes contribute to alter the shape of the expansion curve in actual gas engines. At G a phenomenon occurs, with which nothing in Fig. 121 corresponds. The exhaust valve opens prematurely, while the gases are still at a high temperature and tension, and the pressure falls suddenly, before expansion is completed; the gases escape into the atmosphere, instead of continuing to act upon the piston. At H the end of the stroke is reached, and the gases of combustion are discharged along the return line from H to A. At the beginning of the return stroke this line is above the atmospheric pressure to which the gases are in theory reduced at the end of expan-

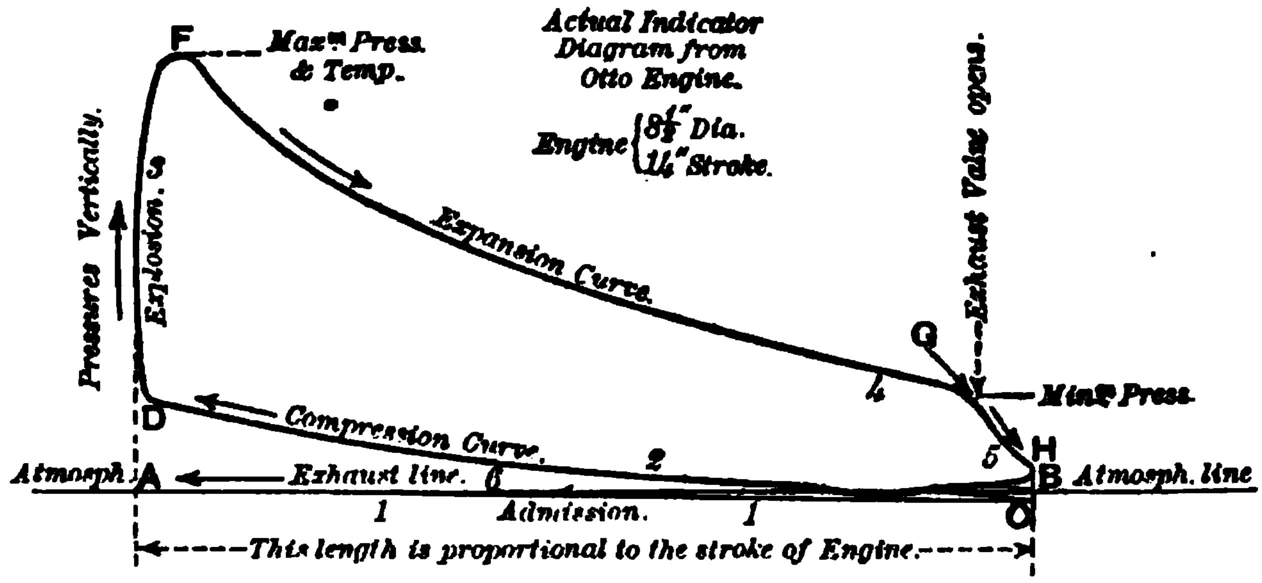

Fig. 122.—Otto Engine—Actual Indicator Diagram—Single Cylinder—Single Acting. (The figures indicate sequence of operations.)

sion, and there is a certain amount of back pressure, or pressure retarding the motion of the piston.

This indicator diagram may be taken as a typical representation of the curves of pressure usually obtained in an Otto engine during two revolutions. The chief reasons for the variations in this, as compared with a theoretical cycle, are :—

1. Explosion is not instantaneous, and continues after the piston has begun to move out.

2. Combustion is not completed till some time after the beginning of the stroke, and the whole heat is not developed instantaneously.

3. Heat is carried off by the walls and the water jacket, to reduce the temperature within practicable limits.

4. Expansion is never adiabatic, and the whole heat expended or evolved from the gas is not absorbed in doing work.

5. Expansion is not continued till the pressure of the gases is reduced

to atmospheric, but they are discharged much before their full pressure has been utilised in work on the piston.

Ayrton and Perry.—A very complete and careful study of a 6 H.P. Otto gas engine indicator diagram will be found in a paper by Messrs. Ayrton & Perry, in the *Philosophical Magazine* for July, 1884. The authors consider, first, the action in the cylinder and the nature of the working fluid, both before and after combustion; next, the shape of the indicator diagram as regards the compression and expansion of the mixture, and the influence of vibrations in the indicator spring. Formulæ are given for calculating the curves. The heat imparted to the fluid, determined from its volume and pressure, is also studied, as well as the total heat and work during the cycle, and the loss of heat during compression and by radiation.

Formulæ for Efficiencies.—Although the formula $\frac{T_1 - T_0}{T_1}$ applies equally to all heat engines, there are various types of gas motors, each utilising differently the heat supplied. In practice they are classified under four heads. In each of these types the indicator diagram varies slightly in shape, and the actual efficiency may be expressed by a different formula. The formulæ of efficiency now generally used in calculating the work obtained in theory from a gas engine were originally drawn up by Professors Schöttler and Witz, and Mr. Dugald Clerk, from whose able generalisations the following figures are taken:—

The first three types of gas engines are direct-acting, and the heat supplied acts directly by expansion of the gas upon the piston; the fourth is indirect-acting, the expansion of the gases forces up the piston, but no work is done except during its descent. The formula for calculating the maximum theoretical efficiency is, as already given, $\frac{T_1 - T_0}{T_1}$, in which T_1 represents the highest absolute temperature attained by the gases, T_0 the temperature (absolute) to which they fall after doing work on the piston, and $1 - \frac{T_1 - T_0}{T_1}$ the percentage of heat utilised. The same formula may be differently stated, thus—

$$\frac{Q}{1 + n} = c_v (T_1 - T_0)$$

or—The total quantity of heat developed by the explosion of the gases (Q) divided by the weight of the charge (1 of gas plus n dilution of air) is equal to the highest absolute temperature of the gases T_1, less the lowest absolute temperature T_0, multiplied by their specific heat at constant volume c_v. The specific heat of the gases at constant volume is taken, because it is assumed that the whole of the heat is added before the piston has moved. From the quantities of heat the pressures can be deduced, according to

Boyle's law. Thus $p_1 = p_0 \frac{T_1}{T_0}$ or—The highest pressure p_1 developed by the explosion of the gases is equal to the initial pressure p_0, multiplied by the ratio between the highest and lowest absolute temperatures. In the following formulæ the pressures are omitted, but they can be worked out by the student from the temperatures.

1. **The first type** of gas motor is the direct-acting, non-compression engine. Here the gases are not compressed before ignition, but are admitted into the cylinder at atmospheric pressure and ordinary temperature. All the heat is then generated at once, and the gases expand, driving the piston to the end of the stroke. The best example of this sequence of operations is furnished by the original Lenoir engine (see diagram, p. 34). In its cycle there are three important temperatures—T_0 the initial temperature of the gases admitted into the cylinder, T_1 the highest temperature during explosion, and T_2 the temperature of the gases at release, after they have done work on the piston. In theory T_2 should be equal to T_0—that is, the gases should be reduced to their original atmospheric temperature. In practice this is never possible, but they are always discharged at a higher temperature than T_0. Q represents the quantity of heat added from the source of heat (in heat units or calories), Q_e the quantity discharged to the exhaust, Q_c the quantity turned into work, and γ the ratio between the specific heat of the gases at constant volume (c_v) and at constant pressure (c_p). Thus—

$$Q = c_v(T_1 - T_0).$$

The formula for actual efficiency E of this class of engine is—

$$E = \frac{c_v(T_1 - T_0) - c_p(T_2 - T_0)}{c_v(T_1 - T_0)} = 1 - \gamma\left(\frac{T_2 - T_0}{T_1 - T_0}\right) = 1 - \frac{Q_e}{Q}.$$

$$Q_c = Q - Q_e.$$

2. In the **second type** of engine the gases are compressed before ignition, and explosion takes place at constant volume. To the three temperatures given above, and always to be taken into account in estimating the heat efficiency of any engine, the compression of the gases before ignition adds a fourth, T_3 = temperature of compression. Work being done on the gas by driving the particles closer together, heat must be developed. This rise in temperature is calculated by multiplying the original temperature T_0 by the difference in the volume of the gases before and after compression, raised to the power of the ratio of the specific heats minus 1. The temperatures are here obtained from the volumes, according to Boyle's law. The formula for calculating this temperature of compression is—

$$T_3 = T_0\left(\frac{v_0}{v_1}\right)^{1\cdot408 - 1 = \cdot408}$$

where v_0 is volume before compression, v_1 is volume after compression. The Otto four-cycle engine is the best example of this type (see diagram, p. 94). Thus—

$$Q = c_v(T_1 - T_3), \qquad Q_e = c_p(T_2 - T_0), \qquad Q_c = Q - Q_e.$$

The actual efficiency of this type is—

$$= \frac{c_v(T_1 - T_3) - c_p(T_2 - T_0)}{c_v(T_1 - T_3)} = 1 - \gamma\left(\frac{T_2 - T_0}{T_1 - T_3}\right) = 1 - \frac{Q_e}{Q}.$$

3. The **third type** represents an engine in which the gases are compressed before ignition, as in the second type, but, instead of exploding, they burn at constant pressure. They enter the cylinder as flame, and drive the piston forward, not by the force of the explosion, as in the two former types, but by the expansion of the burning gases. It seems at first as though this type ought, in accordance with the theories hitherto laid down, to give a very low efficiency—that is, to utilise a very small proportion of the heat supplied to it, because there is a constant temperature of combustion during the forward stroke, instead of an instantaneous temperature of explosion. The highest temperature attained is not very great, and there is less range than in the other types. It is, however, an engine giving excellent results in theory, and it is difficult to understand why these results are not realised in practice. The working defects are attributed chiefly to insufficient compression. The efficiency depends, not on the highest temperature attained, but upon the amount of compression, and the greater the compression the greater the heat. In this class of engine, therefore, the usual rule is reversed, and an efficient cycle is obtained with a low temperature of explosion T_1. The best example of this type is the Simon engine (see p. 51). In the formula the ratio of specific heat does not appear, because the burning gases are at a uniform temperature throughout the stroke, and all the operations are effected at constant pressure:—

$$Q = c_p(T_1 - T_3), \qquad Q_e = c_p(T_2 - T_0), \qquad Q_c = Q - Q_e.$$

$$\text{Efficiency } E = \frac{c_p(T_1 - T_3) - c_p(T_2 - T_0)}{c_p(T_1 - T_3)} = 1 - \left(\frac{T_2 - T_0}{T_1 - T_3}\right) = E = \frac{Q_e}{Q}.$$

4. **Atmospheric Gas Engines.**—To this class belong engines in which the action of the gas upon the piston is indirect, and work is obtained, not by expansion, but by the formation of a vacuum under the piston. Theoretically, this type is the most perfect of all, because of the high explosion pressure, and the apparently unlimited expansion, but this great expansion can never be utilised in practice. A piston of undefined length, permitting the gases to expand until their pressure falls to atmosphere, would be necessary to utilise fully the power developed, and this is impossible under working conditions. As the

The following table gives the heat balance of four different English engines, showing the quantity of heat developed, and the proportions of waste, and of useful work obtained. It is taken from Professor Kennedy's Trial of a Beck engine, and the Trials of the Society of Arts, 1888.

	Beck.	Griffin.	Atkinson.	Otto-Crossley.
Heat developed per explosion,	19,980 ft.-lbs. 100 %	20,650 ft.-lbs. 100 %	13,280 ft.-lbs. 100 %	34,040 ft.-lbs. 100 %
,, converted into work,*	3,870 ,, 19·4 %	4,350 ,, 21·1 %	3,390 ,, 25·5 %	7,515 ,, 22·1 %
,, carried off in cooling jacket water,	6,610 ,, 33·0 %	7,280 ,, 35·2 %	3,590 ,, 27·0 %	14,700 ,, 43·2 %
,, carried off at exhaust,	8,570 ,, 42·9 %	8,220 ,, 39·8 %	5,030 ,, 37·9 %	12,100 ,, 35·5 %
,, unaccounted for,	930 ,, 4·7 %	820 ,, 3·9 %	1,270 ,, 9·6 %	·8 % over balance
Diameter of cylinder,	7·5 inches.	9·02 inches.	9·5 inches.	9·5 inches.
Stroke,	15 ,,	14 ,,	12·43 ,,	18 ,,
Number of revolutions,	206·5	198	131	160
Indicated horse-power,	8·05	15·47	11·15	17·12
Brake horse-power,	6·31	12·51	9·48	14·74
Mechanical efficiency,	87 per cent.	85 per cent.	85 per cent.	86 per cent.

* Taking I.H.P. for the work.

gases are not previously compressed, there is no temperature of compression, but another temperature must be reckoned, T_4, representing the temperature of the gases after the exhaust has opened, but before they are compressed by the atmosphere, and restored to their original condition. The heat quantities are represented by—

$$Q = c_v (T_1 - T_0), \qquad Q_c = c_v (T_2 - T_4), \qquad Q_e = Q - Q_c.$$

$$\text{Efficiency } E = 1 - \left(\frac{T_2 - T_4}{T_1 - T_0}\right) = \frac{Q_e}{Q}.$$

These formulæ will be best understood, if calculated and expressed in figures. The temperature of explosion in most gas engines is usually taken at from 1,000° C. = 1,273° abs. to 1,600° C. = 1,873° abs. The initial temperature is commonly assumed to be from about 12° C = 285° abs. to 18° C. = 291° abs. The initial atmospheric pressure is taken at 14·7 lbs. per square inch; the volume of the cylinder is reckoned in cubic feet or cubic metres. In an experiment made on a 4 H.P. Otto engine by Dr. Slaby, the absolute temperatures were computed as follows:—

Initial temperature, ...	T_0,	400° C.
Temperature of explosion, ...	T_1,	1,504° C.
Temperature at opening of exhaust, ...	T_2,	1,068° C.
Temperature of compression, ...	T_3,	400° C.

The foregoing table gives the heat balance of four different English engines, showing the quantity of heat developed, and the proportions of waste, and of useful work obtained. It is taken from Professor Kennedy's trial of a Beck engine, and the trials of the Society of Arts, 1888.

The actual efficiency calculated numerically (see formula of the second type) is—

$$E = \frac{0{\cdot}192\,(1{,}504° - 400°) - 0{\cdot}264\,(1{,}068° - 400°)}{0{\cdot}192\,(1{,}504° - 400°)} = 1 - 1{\cdot}375\left(\frac{1{,}068° - 400°}{1{,}504° - 400°}\right),$$

$$\text{or} \quad E = \frac{211{\cdot}96 - 176{\cdot}35}{211{\cdot}96} = 0{\cdot}168 = 1 - 1{\cdot}375 \times {\cdot}605 = 17 \text{ per cent.}$$

From the above formulæ of efficiencies, it is evident that, in order to obtain a sufficient fall in temperature, it is of great importance to keep the initial temperature of the gases low. In theory the efficiency of the engine depends on the range of temperature, and the lower the initial temperature, and the higher it can be raised by explosion, the better. Much stress is therefore laid by all authorities upon introducing the gases into the cylinder at as low a temperature as possible. The utilisation of the heat in theory depends on the difference

between the maximum temperature and the temperature of admission. In practice, however, the hotter the gases (after explosion), the greater will be the difference in temperature between them and the cylinder walls; consequently the waste will also be greater, because they will part with more heat to the water jacket. To obtain an economical working cycle, all losses of heat should be reduced as much as possible. These are, the exposure of a large area of cylinder surface to the hot gases, and the length of time during which the exposure lasts. The causes to which waste of heat are attributed will be studied in the next chapter.

CHAPTER XVI.

EXPLOSION AND COMBUSTION IN A GAS ENGINE.

CONTENTS.—Definition of Terms—Rate of Inflammability in Gases—Experiments by Bunsen, Mallard and Le Chatelier, Berthelot and Vieille, Witz, Clerk—Boston Trials—Mathot's Pressure Recorder—Bairstow and Alexander—Experiments on Products of Combustion, Grover — Haber — Petavel — Burstall on Measurements of Temperature—Gas Engine Research Committee—Münzel's Criticisms —Meyer on Compression—Clerk on Internal Combustion Motors—Pre-ignition —Wall Action in Gas Engine Cylinders—Loss of Heat—Variations in Expansion Curve — Stratification — Dissociation — Cooling Action of Walls — Increase of Specific Heat—Movements of Heat—Effect of Time.

THE phenomena taking place and work obtained in a heat engine have now been shown to depend on the development and utilisation of heat. Since heat in the cylinder is obtained by the ignition, explosion, and combustion of a certain quantity of air and gas, the character of these phenomena, the strength of the explosion, and speed of propagation of the heat through the gas, are of the utmost importance. For many years they have engaged the attention of scientific men. By careful study and observation, a sufficient number of exact experimental facts have been accumulated to determine approximately the action of gas in an engine cylinder.

Definition of Terms.—Before proceeding to consider these phenomena, it will be well to define the different expressions generally used. Four terms are employed to denote the effects produced by heat in the cylinder of a gas engine—1, Ignition; 2, inflammation; 3, explosion; 4, combustion. Ignition takes place when sufficient heat is communicated by a flame, electric spark, or hot tube, to the gaseous mixture to fire it. Inflammation is the subsequent spreading of the flame throughout the gas, or its propagation from one particle to another, till the whole volume is alight. Explosion follows when the mixture is completely inflamed, and the maximum pressure attained. When all the gas in a cylinder is thoroughly alight, the particles are driven widely apart, and thus the moment of complete inflammation will also be that of maximum pressure. Complete inflammation and explosion are thus practically simultaneous. Combustion is complete, when all the chemical changes have taken place, and the gases have been reconstituted as water vapour (H_2O) and carbon dioxide gas (CO_2). This moment

may not coincide in point of time with explosion. The chemical recombination of the gases, and consequently the evolution of all the heat contained, is almost always delayed in a gas engine until an appreciable time, or fraction of a second, after the maximum pressure is developed, and the piston has begun to move out, as shown by the indicator diagram.

Velocity of Flame Propagation—Bunsen.—It is at the moment when explosion occurs that the maximum pressure is reached, and probably also the maximum temperature.* The importance of this temperature has been proved theoretically in the preceding chapter, and many experiments have been made to determine it, because it marks the rate of inflammation, or of propagation of the flame. The celebrated chemist, Bunsen, was the first to calculate the rate of flame propagation —or of inflammability—in a gas. He confined the mixture in a vessel having a very small orifice, and the gas was ignited as it passed out. The mouth of the orifice was reduced till the pressure of the issuing flame was exactly equal to that of the gas inside, and as soon as the balance of pressure was established, the flame spread back till it had ignited the gas in the vessel. The method of ignition formerly used in the Koerting engine was somewhat similar. The rate at which the gas issued from the vessel being known, the speed of the flame, as propagated back through the mixture, was calculated from it. By these means Bunsen determined the velocity of propagation, or the inflammability of a gaseous flame. With a mixture of 2 volumes hydrogen and 1 volume oxygen, he found it to be 34 metres = 111·5 feet per second; with carbon monoxide it was 1 metre = 3·28 feet per second.

Mallard and Le Chatelier.—Later researches have shown that these figures are not accurate. The instrument then used could not be wholly relied on, because the external air cooled the flame as it issued from the orifice, and affected the results. A series of elaborate experiments were carried out by MM. Mallard and Le Chatelier with a long tube filled with an explosive mixture, closed at one end, and communicating through the other with the open air. The period of explosion, or the time occupied by the flame in travelling through the tube, was marked by revolving drums and tuning forks, the latter being the best instruments for measuring, by their vibrations, fractions of a second. The drums revolved on the same shaft, close to either end of the tube, and a wavy line was traced upon them by the vibrations of the tuning forks, set in motion by the explosion. As soon as the gas at

* Dr. Slaby says that "combustion is completely ended after a fractional portion of the stroke, from 0·03 to 0·06 of a second."—*Calorimetrische Untersuchungen*, p. 161. The latest authorities do not concur in this opinion.

one end of the tube was ignited, it moved a small pencil, and marked the drum revolving at that end. A second pencil made a similar mark on the drum at the other end, when the flame had passed through the length of the tube. The distance between the two marks, measured on the vibrating line traced by the tuning forks, gave the time of propagation of the flame. With the same mixture of hydrogen and oxygen as that used by Bunsen, Mallard and Le Chatelier found the velocity to be 20 metres = 65·6 feet per second, and with carbon monoxide 2·2 metres = 7·2 feet per second, or a speed double that given by Bunsen.

These pure explosive mixtures are too strong to be used in a gas engine, as air is necessary to dilute the gas, and the mixture becomes immediately weakened with a large proportion of non-explosive nitrogen. MM. Mallard and Le Chatelier, therefore, varied the strength of the mixture. With 1 vol. hydrogen mixture (*i.e.*, 2 vols. hydrogen to 1 of oxygen) and 1 vol. oxygen, the rate of flame propagation was 10 metres = 32·8 feet per second. The highest velocity was found to be the mixture of 1 vol. hydrogen to 1 vol. oxygen, originally used by Bunsen, but to obtain a standard for the dilution commonly employed in a gas engine, the experimenters combined hydrogen with air in the proportion of 2 vols. hydrogen to 5 of air. The table on p. 319 (from Clerk) shows the velocity of flame with hydrogen and various volumes of air.

In these experiments the explosive mixtures were at constant presure; the end of the tube being open, the ignited gases issued from it in a continuous stream, and did external work against the pressure of the atmosphere. When both ends of the tube were closed, and the mixture was ignited at constant volume, the velocity with which the flame was propagated was very much greater. A speed of 1,000 metres = 3,280 feet per second, instead of 20 metres, was verified with hydrogen explosive mixture (2 vols. H and 1 vol. O). When the hydrogen was diluted with air, the speed was 300 metres = 984 feet per second. This great difference in the rate of flame propagation is attributed by MM. Mallard and Le Chatelier to inflammation taking place, not only by the projection of the flame from one particle to another, but by the expansion of the particles through the heat generated. As they ignite, they rise in temperature and pressure, and the propagation of the flame is thus assisted. When the mouth of the tube is closed, and the particles cannot expand freely into the atmosphere, the ignited portions of the gas are forcibly projected into the parts not yet kindled. These experiments prove the greatly increased velocity of flame propagation when the volume of the gases is constant, and, therefore, the value of ignition at the dead point in a gas engine.

TABLE OF VELOCITY IN DILUTED MIXTURES (*Mallard and Le Chatelier*).

	Velocity per Second.	Velocity per Second.
Mixture of 1 volume hydrogen and 4 volumes air,	2 metres.	6·5 feet
,, ,, ,, ,, 3 ,,	2·8 ,,	9·1 ,,
,, ,, ,, ,, $2\frac{1}{4}$,,	3·4 ,,	11·1 ,,
,, ,, ,, ,, $1\frac{6}{7}$,,	4·1 ,,	13·4 ,,
,, ,, ,, ,, $1\frac{1}{2}$,,	4·4 ,, *max.*	14·4 ,, *max.*
,, ,, ,, ,, 1 ,,	3·8 ,,	12·4 ,,
,, ,, ,, ,, $\frac{1}{2}$,,	2·3 ,,	7·5 ,,

Berthelot and Vieille.—A series of valuable experiments were also carried out by MM. Berthelot and Vieille, to determine the rate of flame propagation (or of complete combustion, since in this case the two terms are synonymous) of gases at constant volume in a closed vessel. The time of explosion was determined in receivers of three different capacities—namely, 300, 1,500, and 4,000 cubic centimetres. Two of the vessels were cylindrical and the third spherical, and each was fitted with a registering piston. At either end they terminated in a short tube; at the further end of one an electric spark was produced for firing the mixture, the other contained the piston. The lengths of the igniting tube, the cylinder, and the tube containing the piston being known, the time occupied by the flame in passing through the gas, from the point of ignition till the explosion reached and forced up the piston, could be calculated. The experiments were made with a variety of chemical compounds, such as nitric oxide, cyanogen, and compounds of hydrogen, oxygen, carbon, and nitrogen. The larger the capacity of the vessel or receiver, the longer time was found to elapse, with every mixture, between the ignition of the gas and the attainment of maximum pressure. This agrees with Gay-Lussac's law, since the smaller the vessel for a given volume of gas, the greater will be the increase in pressure produced by the high temperature of ignition. The effect of the composition of the mixture, and of the more or less perfect combustion obtained by adding oxygen in exact proportion or in excess, were also noted.

One of the most important practical results of these experiments, with regard to the phenomena in a gas engine, was obtained with the products of combustion. By using a mixture of the chemical elements contained in these products, and observing the time occupied by the projection of the flame, MM. Berthelot and Vieille proved that the rate of flame propagation in such compounds was slower than with pure mixtures, representing the fresh charge of gas and air in a cylinder. Dilution with the exhaust products, therefore, whether advantageous or

not, must retard the rate of combustion, because these products contain an excess of some of the gases. With gases not perfectly combined, and where combustion is incomplete, the rate of flame propagation was found to be most rapid, perhaps because partial dissociation takes place, and retards total combustion. MM. Berthelot and Vieille are of opinion that, by the ignition of the gas and the high temperature produced in the closed vessel, what they term an "explosive wave" is formed, the velocity of which is greatly in excess of the ordinary velocity of flame propagation. It is generated by the shock of igniting a large portion of the inflammable gas at once; the flame is propagated with a velocity due to the shock, almost as great as the velocity of combustion. For hydrogen, the velocity of this explosive wave is 2,810 metres = 9,216 feet per second; for carbon monoxide, it is 1,689 metres = 5,539 feet per second.

Witz.—Valuable as these theoretical determinations are in studying the theory of combustion, practical experiments are needed to calculate the actual result of generating heat in a gas, by combustion in an engine cylinder. With this object, Professor Witz undertook a number of valuable experiments to illustrate the action of ordinary lighting gas, when mixed with various proportions of air, and ignited. He also desired to show the influence of nitrogen in affecting injuriously the true rate of flame propagation. In MM. Berthelot and Vieille's experiments, the gas was always at constant volume, and no expansion was possible. M. Witz used an ordinary cylinder and piston, and the charge was allowed to expand freely. The first tests were made with a mixture of carbon monoxide and air; the calorific value at given temperatures of each chemical element was previously determined. A basis being thus obtained for exact computation, lighting gas was used for the rest of the trials, and the differences in chemical composition neglected. Professor Witz attached a tuning fork to the indicator diagram, in order to measure, not only the pressure developed by the explosion, but the fractions of a second before the maximum pressure was attained. Taking the ratio of this time to the length of stroke of the piston, he reckoned the speed of expansion thus—

$$\frac{\text{Length of stroke in feet}}{\text{Duration of explosion in seconds}} = \text{speed of expansion in feet per second.}$$

Calculating the work done from the area of the diagrams, and its ratio to the theoretical work obtained from the number of calories in a given volume of gas and air, Professor Witz found that the percentage of work actually done increased in proportion to the speed of expansion. Some of the results of his able experiments made with lighting gas mixed with varying proportions of air are summed up in the table on p. 321.

In both these series of experiments, the volume of the charge was the

same—namely, 2·081 litres = 0·73 cubic foot. The richness of the mixture, the length of stroke, and the duration of the explosion varied. Fig. 123 shows a diagram of the expansion, with the vibrations below of the tuning fork used as a measure of time. Each vibration corresponds to $\frac{1}{128}$ of a second. The diagram gives the pressures and volumes, the lower waves mark the time occupied in expansion. The atmospheric line Hx shows that expansion was continued to below atmospheric pressure. From these and many similar experiments, Professor Witz has formulated the two following laws concerning the expansion of gases:—

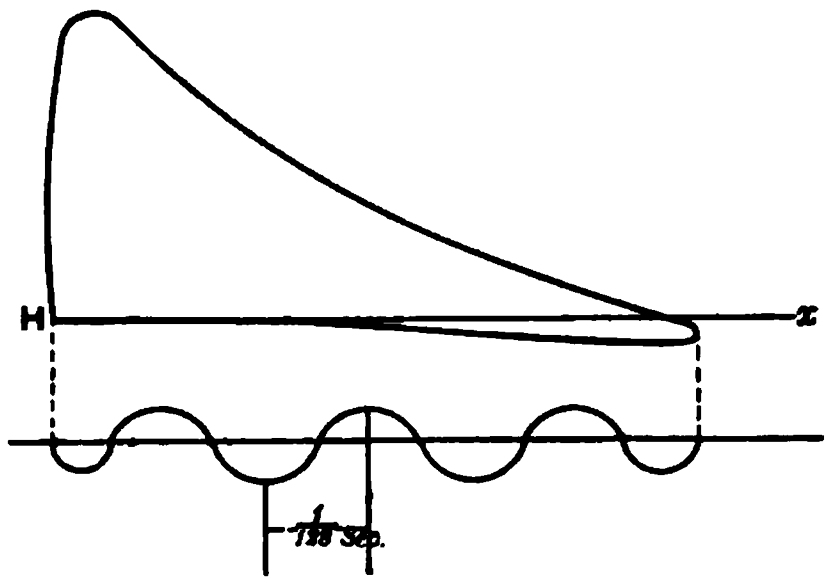

Fig. 123.—Witz Time Diagram.

I. The utilisation of the heat supplied to the engine increases with the speed of expansion.

II. The greater the speed of expansion, the more rapid will be the combustion of the explosive mixtures.

Experiments of Professor Witz on Town Gas, with Constant Mixture of 1 Volume Gas to 9·4 Volumes Air.

[Vol. of mixture, 2·081 litres.]

Duration of Explosion in Fractions of a Second, taken from Diagrams.	Length of Stroke of Piston.	Speed, Metres per Second.	Theoretical Work.	Work calculated from the Diagrams.	Utilisation or Per Cent. of Work done. Ratio of columns *d* and *e*.
a.	*b.*	$\frac{b}{a} = c.$	*d.*	*e.*	$\frac{e}{d}$.
Second.	Millimetres.	Metres.	Killogram-metres.*	Killogram-metres.	Per Cent.
0·48	122	0·25	446	5·3	1·2
0·47	127	0·27	446	5·3	1·2
0·40	127	0·32	446	7·0	1·5
0·39	132	0·34	446	6·6	1·4
0·31	140	0·45	446	7·8	1·7
0·23	147	0·64	446	10·8	2·4

[1 Litre = 61·025 cub. ins.]

Mixture of 1 Volume Gas to 6·33 Volumes Air.

[Vol. of mixture, 2·081 litres.]

0·15	259	1·7	633	17·6	2·7
0·09	259	2·9	633	40·1	6·2
0·06	259	4·3	633	50·5	7·9
0·06	259	4·8	633	50·7	9·3

* 1 kilogrammetre is 1 kilogramme × 1 metre = 2·20 lbs. × 3·28 feet or 7·2 foot-lbs. of work done per second (see p. 271).

This speed of expansion, which the above table shows to have so important an effect on the proportion of actual to theoretical work, Professor Witz considers to be only the expression under another form of the great influence of the walls, and their cooling action upon the hot gases. "The maximum explosive pressure," he says, "depends on the ratio of the cooling surface of the receiver (or cylinder) to the volume of the gas." In his opinion, nearly all the differences between the action of the gases, in theory and in practice, in the cylinder of an engine, which have hitherto been so difficult to account for, may be attributed to the effect of the walls.

Clerk.—Mr. Dugald Clerk was led by his experiments to almost the same conclusions as Professor Witz, though he approached the subject from another point of view. He considered that, to understand the action of gas in a cylinder, it was necessary to determine, not only the time required to attain maximum pressure, but also the duration of this pressure. As it is the force of the explosion which produces effective pressure on a piston, it seems as if, the stronger the mixture employed, the more useful within working limits will be the effect; but experience has shown this view to be erroneous. The greater amount of work is obtained from the mixture giving the maximum pressure, in proportion to the surfaces, and maintaining that pressure during the longest period of the stroke. The higher the explosive pressure and temperature generated, the more rapidly will heat be carried off by the cylinder walls, and this is one reason for the difference between theory and practice in an engine cylinder. Theoretically the highest explosive pressures are the best; but in practical working they are not found the most effective for power.

Mr. Clerk's experiments were made with a small cylinder without a piston, filled with different explosive mixtures, connected to an indicator, the drum and paper of which were made to revolve so that each tenth of a revolution occupied 0·033 second. The pressure of the explosive gases forced up the indicator pencil, and by dividing the area of the moving drum, on which the pencil traced curves, into sections, the time occupied by the explosion, and cooling or reduction of pressure of the gases, could be estimated within $\frac{1}{100}$ of a second. On this diagram the ordinates represented pressures, and the abscissæ the time of explosion in fractions of a second. The maximum explosive pressure was developed in a closed vessel, and therefore at constant volume; and the cylinder having no piston, no heat was expended in doing work. The diagrams showed that the pressures of the gases fell much more slowly than they rose. The maximum pressure was produced in 0·026 second after ignition; the fall to atmospheric pressure and temperature occupied 1·5 seconds, or nearly 60 times as long. Without previous compression of the gases,

the highest pressure obtainable with a dilution of 1 part gas to 5 parts air was only 96 lbs. per square inch; with compression and a much weaker mixture, this pressure was nearly doubled. The "critical mixture," or the weakest dilution of gas and air that will ignite, varied according to the quality of the gas used. With Oldham gas a charge of 1 part gas to 15 of air ignited, and the pressure produced was 40 lbs. per square inch above atmosphere. With Glasgow gas the critical mixture was 14 of air to 1 of gas, and the pressure produced was 52 lbs. per square inch.

To determine the best mixture for use in a non-compressing gas engine Mr. Clerk supposed 1 cubic inch of gas to be diluted with air in the ratio of 13, 11, 9, 7, and 5 cubic inches, and these mixtures to be admitted into cylinders having pistons, the areas of which per square inch were in proportion to the strength of the dilution. Thus the charge of 14 cubic inches—viz., 1 volume gas to 13 volumes air—would be admitted into the cylinder having a piston surface of 14 square inches, the depth of the mixture in the cylinder being always 1 inch. The maximum pressure and time of explosion of these mixtures were as follows:—

EXPERIMENTS BY MR. CLERK ON EXPLOSION AT CONSTANT VOLUME IN A CLOSED VESSEL WITHOUT PISTON. MIXTURES OF AIR AND GLASGOW COAL GAS.

Mixtures used.	Maximum Pressure above Atmosphere in lbs. per sq. inch.	Time of Explosion, or time elapsing between Ignition and Maximum Pressure.
1 volume gas plus 13 volumes air, .	52 lbs.	0·28 second.
1 ,, ,, 11 ,, .	63 ,,	0·18 ,,
1 ,, ,, 9 ,, .	69 ,,	0·13 ,,
1 ,, ,, 7 ,, .	89 ,,	0·07 ,,
1 ,, ,, 5 ,, .	96 ,,	0·05 ,,

Temperature before explosion, 18° C. = 291° abs. Pressure before explosion, atmospheric.

The highest pressures, giving respectively 756 lbs. and 728 lbs. upon the total piston area, were obtained with a dilution of 11 and 13 volumes of air to 1 of gas. The stronger mixtures gave lower pressures, because (being contained in smaller cylinders) the pressure, to a uniform depth of 1 inch, was exerted over a smaller piston surface. Taking one-fifth of a second as the mean time occupied by the piston in making its forward stroke, the pressure of each gas, when that time had elapsed after the

attainment of maximum pressure, was then computed from the indicator diagram. Multiplying this pressure by the piston area, the weakest mixtures gave the highest relative pressures at this point in the stroke, showing, according to the following table, that these weak mixtures maintained their pressures longest:—

EXPERIMENTS BY MR. CLERK ON MIXTURES OF AIR AND GLASGOW GAS AT CONSTANT VOLUME (*with same Apparatus*).

Mixture.	Pressure produced on piston by 1 cub. in. gas.	Pressure in lbs. per sq. in., 0·20 second after max. pres.	Pressure remaining upon piston area 0·20 sec. after max. pressure.	Mean Pressure.
1 volume gas plus 13 volumes air,	728 lbs.	43 lbs.	602 lbs.	665 lbs.
1 " " 11 "	756 "	48 "	576 "	666 "
1 " " 9 "	690 "	47 "	470 "	580 "
1 " " 7 "	712 "	55 "	440 "	576 "
1 " " 5 "	576 "	57 "	342 "	459 "

In experiments with pure hydrogen diluted with air, the pressures were much lower than with gas.*

Boston Experiments.—Trials were also carried out in 1898 at the Engineering Laboratory of the Massachusetts Technological Institute, Boston, to determine the interval of time in tenths of a second elapsing between ignition and the attainment of maximum pressure, and also the pressure, at each twelfth of a second, of explosive mixtures of lighting gas and air in various proportions. The pressures were shown on indicator diagrams, while a marker attached to a tuning-fork traced simultaneously a time wave line of vibrations equal to one-sixtieth of a second. The explosions took place in a cast-iron cylindrical vessel without a piston, of 310 cubic inches volume, to which a mercurial gauge for recording the pressures, an air and a vacuum pump, and two electric batteries for firing the charge and keeping the tuning-fork in vibration, were connected. The pressure-recording apparatus consisted of an indicator paper fixed on a circular revolving disc driven at a uniform speed, on which by a special arrangement the tuning-fork traced a succession of contiguous lines. Thus the time and pressure lines were recorded simultaneously, the atmospheric line and the diagrams of pressure both being circular. Only the pressures obtained during the first fifth of a second

* For further details see *The Gas Engine*, Dugald Clerk, pp. 95 to 104, fifth edition.

were studied, as in that time an ordinary gas engine has completed its stroke.

To determine the pressures the cylinder was first thoroughly cleansed, then connected only to the vacuum pump, and the air exhausted to about one-sixth of an atmosphere. Into the partial vacuum thus formed, giving a pressure of 5 inches of mercury, gas was admitted, and the pressure raised to atmospheric, thus producing a mixture of 1 part of gas to 5 of air. The charge was then fired electrically, the tuning-fork set in vibration, and diagrams of pressure were taken. The proportion of gas to air could be varied by the vacuum in the pump. In the original paper the results obtained for mixtures of from 3 to 14 parts by volume of air to 1 of gas are given in a table. During one second the moment of explosion, and of attainment of maximum pressure and of mean pressure for each twelfth of a second, were recorded, and the pressure also noted for each sixtieth of a second. The maximum pressure, and time required to attain it, the mean and final pressures for the first fifth of a second of the stroke, and for the fifth of a second after maximum pressure, were tabulated. The mean and final pressures divided by the proportion of gas to air show the relative powers of the mixtures, and their power to resist cooling. The highest maximum pressure, 96 lbs. per square inch, was obtained with 1 part of gas to 5 of air; highest mean pressure, 66 lbs. per square inch, and highest relative pressure, with 1 to 7 of gas and air. A mixture of 1 to 11 of gas and air gave the highest mean pressure in proportion to the gas used, during the fifth of a second after maximum explosion, and also the maximum final pressure, or resistance to cooling. The highest mean pressure, in proportion to the gas burnt, 530 lbs. per square inch, was produced with a mixture of 1 of gas to 9 of air.

Mathot's Explosion Recorder.—For the purposes of such experiments, a useful little instrument has been invented by M. Mathot, of Brussels, to record continuously the number of explosions in an engine cylinder, in the same way as the pressures. The apparatus, which is mounted on the explosion chamber of the engine, consists of a small vertical water-jacketed cylinder, the piston and rod of which are connected to a small pointer above it. A drum at the side carries a strip of paper, which is continuously unrolled by means of clockwork mechanism. The motion of the drum and paper is horizontal, that of the pointer vertical. The force of each explosion in the motor cylinder throws up the piston of the small cylinder, and with it the pointer, which traces a series of vertical lines on the paper, each corresponding in height to the strength of the explosion recorded. A stationary pointer marks at the same time the line of atmospheric pressure on the paper as it unrolls. The piston is brought back into position by a spring. The clockwork

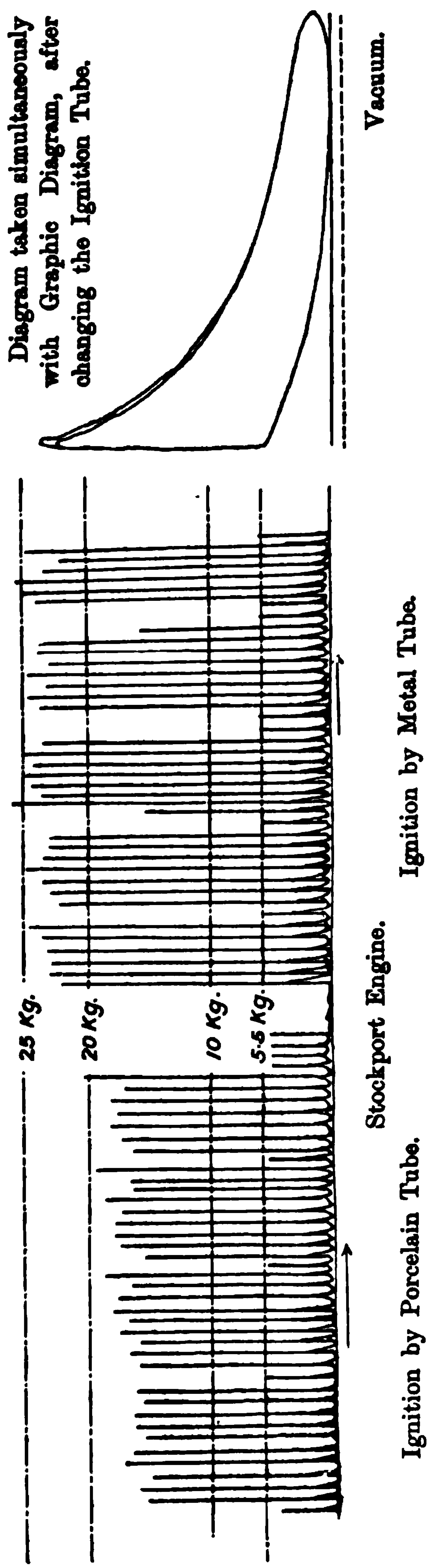

Fig. 124.—Mathot's Diagram of Explosions.

regulating the horizontal movement of the paper over the drum is set in accordance with the number of revolutions of the engine tested. By means of this ingenious little instrument it is possible to study the working of an engine, and to take count of the number of explosions and of miss-fires, the initial and maximum pressure of each explosion, the order in which they succeed each other, and the speed of the engine. Fig. 124 shows a diagram of explosions taken from the Stockport engine tested by M. Mathot, and mentioned at p. 105.

Experiments to determine the cooling action of the walls on the maximum pressure of explosion have been made by Messrs. **Bairstow** and **Alexander.** As in the Boston tests, the mixtures were formed by pumping a partial vacuum in the cylinder, and admitting gas to fill it, then sufficient air to raise the charge to atmospheric pressure; it was then fired electrically. With a ratio of ·225 of gas to air, and no compression, maximum pressures of 50 to 92 lbs. per square inch were obtained. If the air was admitted gently, and the mixture allowed to stand, it was difficult to procure an explosion; but it was easily exploded if the air was pumped in rapidly. When mechanically stirred a mixture of ·215 of gas to air, which would not explode before, gave pressures of 90 and 88 lbs. per square inch.

To determine the cooling effect of the cylinder walls, the duration

of explosion was varied by applying the igniting spark at the end of a telescoping tube, the length of which, and thus the time of ignition, could be regulated. With a mixture of ·17 of gas to 1 of air, the time of explosion was ·035 of a second with a firing tube 8 inches long, and one-tenth of a second with a tube 2 inches or with one 16 inches long. With weaker mixtures explosion lasted from one-quarter of a second with a maximum pressure of 185 lbs. per square inch, to 1·8 seconds with a pressure of 118 lbs. In intermediate tests it was found that the quicker the explosion, the higher were the pressures. Variations in the maximum pressures decreased in proportion to the richness of the mixtures. This was attributed to less difference between the cooling action of the walls and the increase of heat in the cylinder, due to less dissociation of CO_2, the loss and gain of heat tending to counterbalance each other. Corrections of 10 per cent. and less were made for cooling, calculated from the difference in the areas of the pressure diagrams, and from them a new value for the maximum pressures, with allowance for cooling, was obtained. The weaker the mixture used, the smaller was the difference between the actual and the calculated pressures. With the richest mixtures giving high pressures, this difference was attributed by the authors wholly to dissociation, and with weaker mixtures and lower pressures, to the cooling action of the vessel, because at the temperature of 1,200° C. developed with these mixtures dissociation of the CO_2 does not occur. The method of firing at the end of a tube was found to cause the line traced by the explosion curve to fluctuate considerably, especially at the beginning of strong explosions. The fluctuations occurred earlier or later in the explosion line, according to the length of the firing tube.

Experiments on Products of Combustion—Grover.—An interesting series of experiments were carried out at Yorkshire College, Leeds, in 1895, by Mr. Grover,* upon the pressures obtained with explosive mixtures of coal gas and air, when diluted with the products of former combustion. The apparatus used was a closed vertical cast-iron cylinder without piston, of 1 cubic foot capacity. A charge was fired electrically, the temperatures were taken by a thermometer, and the pressures recorded by a Crosby indicator with continuously revolving drum, driven by clockwork. The time was marked by a vibrating spring producing a wave every eighth of a second. A certain proportion of the previous charge being retained, half the volume of air required for dilution was then introduced, next the charge of gas, and lastly the remainder of the air. The author considers that, in a gas engine cylinder, the gas and air are more perfectly mixed with each other than with the residual

* See his paper on "The Effects of the Products of Combustion upon Explosive Mixtures of Coal Gas and Air," reprinted from *The Practical Engineer*, 1895.

charge. With 58 per cent. by volume of the products left in the cylinder, he found that the limit of inflammability was reached, and no ignition could be obtained. He was also of opinion that it is the ratio of air to gas alone which determines the force of the explosion, and he confirmed Mr. Clerk's experiments that, when this ratio is less than 5·7, the charge will not ignite. The different data obtained are carefully plotted in curves and diagrams, and from them the author deduces the following important conclusions:—That the highest pressures are obtained when the volume of fresh air admitted is only a little more than that required for complete combustion; that this proportion should never be more than 5½ times that of the gas, but if this ratio is preserved the charge may be diluted up to 58 per cent. with the products of combustion; that the latter should always take the place of an excess of air, not of the air required for diluting the gas; and when they thus replace an excess of air the time of explosion is much reduced.

The amount of exhaust products left to mix with the incoming charge also influences its composition, according to the action of the governor. As pointed out by Mr. Clerk, if the governor reduces the volume of the fresh mixture, while the volume of the exhaust products remains the same, the charge will be more diluted, and combustion slower. As the fresh charge alone comes in contact with the ignition port, ignition is practically certain, but the flame will spread more slowly. Whether the governor varies the quantity or the quality of the charge its effect, by retarding the maximum pressure and temperature of explosion, cannot be ignored. Professor Boulvin also observes that when the governor acts by cutting out explosions, it does not at the same time control the water circulation, and as much heat is carried off from the cylinder as when an explosion at each motor stroke is obtained. If the gas supply alone is suppressed, cold air is admitted, and also tends to cool the cylinder, and reduce the thermal efficiency.

Experiments on similar lines were made in 1895 by **Haber.** He started with the assumption that with a mixture containing one part of gas to six of air, 1·8 per cent. of methane found in the exhaust showed that 30 per cent. of the methane passed unconsumed through the cylinder, with 15 per cent. resulting loss of heat. Samples of the gases from two Deutz engines, one with a slide valve and "hit-and-miss" governing, the other with lift valves and a graduated cam, were drawn off about 2½ feet behind the exhaust valve, and the proportions of CO, H, and CH_4 they contained were determined. With the latter engine at half load, and with the admission valve half open, the volumetric percentage of the three gases in the exhaust was about equal. At full load, with fully open admission valve, only traces of these gases were found. When the engine was run with a full load, or with no load, the

first charge after several missed explosions did not ignite. The slide valve engine gave similar results. Indicator diagrams taken from it showed that the first explosion after two misses gave a much flatter diagram than the second, which yielded the same diagram as the lift valve engine. There is certainly a connection between this flattened line of combustion and weaker explosion, and the appearance of the combustible gases in the residuum. The loss of heat, calculated from the quantity and chemical composition of the combustible gases in the exhaust, is 5 to 6 per cent., with one-third load on the brake. In later experiments on the same subject, the exhaust gases were sampled by weight instead of by volume, a method which, in Professor Meyer's opinion, gives much more accurate results. A similar method was adopted by him (see p. 335).

Mr. **Petavel**, of Victoria University, has studied the action of gas and air mixtures, when compressed to a pressure of 70 atmospheres =995 lbs. per square inch. Pressures of explosion were thereby produced of 4 to 5 tons per square inch, with a ratio of air to gas of about 6 to 1. With such high pressures, Mr. Petavel found that the loss of heat did not increase in the same ratio as the density of the gaseous mixtures, but at a lower rate. Roughly speaking, if a gas be compressed to one-hundredth its initial volume, the loss of heat to the walls would be only six times greater than without compression.

It is to Professor **Burstall** that the best method of measuring the temperature in the cylinder of a gas engine during the explosion stroke is due. It had previously been found impossible to determine these very high temperatures, owing to their rapid variations, and the high pressures developed. After many trials Mr. Burstall succeeded by means of a modified form of Callendar's electrical thermometer, consisting of a naked platinum wire, 0·0025 inch diameter and ¾ inch in length. A small thermal capacity was essential, as during one stroke, occupying less than one-quarter of a second, the temperature varies 500° C.

The wire was introduced into the cylinder by means of a steel tube, through which leads passed to the measuring instruments. The changes of electrical resistance produced by changes of temperature in the wire were measured by means of a Wheatstone bridge and mirror galvanometer. The thermometer was calibrated by determining its resistance in ice, steam, and sulphur vapour. By special means the galvanometer circuit was closed at any particular point of the explosion stroke. The electrical resistance of the wire at that part having been determined, the corresponding temperature was deduced. In the original paper in the *Philosophical Magazine* for September, 1895, the temperature results are plotted, and may be summarised as follows:—In a 7 H.P. single

cylinder Otto-Crossley engine, of 8½ inches cylinder diameter and 18 inches stroke, working at 120 revolutions and 13 explosions per minute, the temperature in the centre of the clearance space varied during the motor stroke from 1,200° C. at 10 per cent. to 850° C. at 80 per cent. of the stroke.

Gas Engine Research Committee—Professor Burstall's Tests. —These trials have been undertaken by a Committee of the English Institution of Mechanical Engineers to determine the effect produced on the economy of a gas engine by varying the speed, degree of compression, ratio of gas to air, and heat rejected to the walls—*i.e.*, lost to the cooling jacket. The Committee consider that it is impossible to estimate the economy to be obtained from, say, increased compression in internal combustion engines, unless the other working conditions are varied successively, and only one at a time. In most of the experiments hitherto

Fig. 125.—Experimental Gas Engine—Burstall's Tests. 1898, 1901.

published one only of the set of conditions has been altered, all the others remaining constant, as, for instance, in Professor Witz's tests on the influence of speed. Trials of gas engines are much needed, in which a given series of conditions are systematically varied, one at a time. In these tests great care was taken to obtain trustworthy results, the accuracy of any trial being limited by the most inaccurate of the instruments employed.

The experimental 5 I.H.P. gas engine built by Messrs. Fielding & Platt was worked at half power during the first set of trials under varying conditions of speed, compression, and richness of the charge. It is of the ordinary four-cycle type, horizontal, with 6-inch cylinder diameter and 12-inch stroke, and is governed on the "hit-and-miss" principle. To vary the size of the compression space, a packing piece, called a "junk ring" in the drawing (see Fig. 125), was either bolted

to the back of the piston or removed, and compression of the charge from 35 to 90 lbs. per square inch was thus obtained. All the tests were made with lighting gas. The quantity of gas admitted per stroke was regulated by throttling, and the speed varied from 250 to 120 revolutions per minute, by altering the weights on the governor. The gas was measured from a holder of 100 cubic feet, its pressure determined by a U-gauge, and its temperature by placing the bulb of a thermometer in the supply pipe. The air was measured through a meter, into which it was forced by a blower, and the pressure and temperature taken as before. The heat rejected to the jacket water was determined from the quantity and temperature of the latter in and out. The exhaust gases were sampled and analysed. As it was found difficult to get a true sample unmixed with air, a single bubble of gas was taken from the exhaust valve immediately after each explosion, by means of a small electrical relay. A contact was fixed to the valve, and the latter as it lifted closed the circuit and opened a small needle valve, which allowed one bubble of gas to pass to a receiver containing mercury. The gas was thus sampled continuously and automatically. A Wayne indicator, with a rotating piston, was used in the trials, and the diagrams were traced on a sheet of mica coated with smoke. Both indicator and spring were carefully tested, and readings to within a thousandth of an inch obtained. In these earlier experiments the engine worked with hot-tube ignition without a timing valve.

Sixteen trials were made under these conditions. Table No. 2 at the end of the book gives a summary of them, arranged in order of merit of thermal efficiency per B.H.P. The compression of the charge varied from 52 to 105 lbs. per square inch, with a maximum initial pressure of 118 to 286 lbs.; the thermal efficiency, or percentage of heat turned into work on the brake to the heat given to the engine, varied from 17 per cent. to 9·5 per cent., the maximum being obtained at a speed of 107 revolutions per minute, and a compression pressure of 103 lbs. per square inch absolute.

In the second series of tests the air was measured by a wet meter, and the charge fired by electricity. Ignition was obtained from a spark produced by breaking a low potential circuit inside the cylinder. A careful system of insulation by means of mica discs was arranged. The moving contact breaker was worked through a bell crank lever from the exhaust cam, and was found to give perfectly satisfactory results, no failures to ignite having occurred during trials extending over two years. All other working conditions were the same as before. The tests were carried out with successive compressions of 55, 71, 93, and 124 lbs. per square inch absolute. Each set was started with practically the theoretical minimum amount of air required to ignite the gas, and the ratio

of air to gas was then gradually increased. In the first three series, at 55, 71, and 93 lbs. compression pressures, the ratio varied from 5·5 to about 11; in the set at highest pressure the gas was diluted with from 6·5 to about 12 times its volume of air. The ratio was determined by calculating the volume of air from the calculated temperature at the end of the suction stroke, assuming the cylinder to be then filled only with air and gas, and also from the CO_2 in the exhaust gases, but this method was not considered wholly satisfactory by the experimenters.

In Professor Burstall's opinion, these experiments prove that variations in the specific heats of CO_2, oxygen, nitrogen, and water vapour occur at high temperatures, as shown by Mallard and Le Chatelier, and adopts their values, which in Professor Meyer's opinion are somewhat too high. Valuable formulæ will be found at p. 9 of the original Report, for calculating the theory of the gas engine on the assumption of variable specific heats.* "These experiments," says the Reporter, "would tend to prove that for maximum economy the expansion should be nearly an adiabatic." As no trace of carbon monoxide was discovered in the exhaust gases, notwithstanding repeated tests, the conclusion was drawn that combustion did not take place in the exhaust pipe, in this experimental engine. The temperatures were taken according to the method of electrical resistance already described, as used by Professors Burstall and Callender, and a full description is given in the Report. With these very delicate instruments, a range of temperature in the cylinder itself was verified, in one case amounting to 200° C., between the temperature of the innermost core and that close to the walls. The existence of such a variation throughout the cylinder has long been suspected (see p. 347); if it could be experimentally established, it would naturally affect the temperatures as now calculated from the pressures, volumes, and exhaust temperatures. A selection of sixteen of these later trials, taking the highest and lowest in thermal efficiency for each series, and tabulating them in the same way as was done by the author for the former tests, has been added to Table 2.

Münzel.—In criticising this Second Report, Herr Münzel (late of the Gas-Motoren Fabrik, Deutz) objects to the use of so small an engine, because as the ratio of cylinder volume to wall surface varies greatly, according to the size of the engine, the data obtained with a small motor, do not in every respect apply to a large one. Professor Meyer's trials were also carried out on a small engine. The difficulty of submitting a large motor, especially if driven with power gas, to the exhaustive tests made by Professors Burstall and Meyer, has hitherto prevented such trials being

* Calculations of the efficiencies in a gas engine with varying and constant specific heats will also be found in Professor Schimanek's "Versuche mit Verbrennungs-motoren," *Zeitschrift des Vereines deutscher Ingénieure*, vol. xlvii.

undertaken. In the Burstall tests the exhaust valve was, in Münzel's opinion, placed so low in the cylinder that some of the lubricating oil must have been blown out at discharge, in which case either the piston would work dry, and increase the frictional resistance, or if much oil were supplied, it would be gasified, and show a higher than the actual heat efficiency. Electric ignition by magneto-induction is now universal abroad, and Münzel considers that the method employed in these trials would not work well in an engine run continuously, because the projecting steel rods become overheated, and cause pre-ignition. He also deprecates governing on the "hit-and-miss" principle, and takes exception to the method of reducing the compression space and increasing compression. A projecting piece added to the piston has an injurious effect upon the cycle, because it takes up much of the heat of combustion, affects the quantity of gas and air drawn in, and sometimes produces premature ignition. It is the compression space itself which should, if possible, be diminished in size. "Without knowing the exact chemical composition of the gas, I have found," he says, "that the most advantageous compression stands in a certain connection with the heating value of the gas, as shown by a Junkers calorimeter. . . . The best ratio of air to gas may be determined by fixing a throttle valve in the air pipe, and adjusting it until the minimum quantity of gas, at maximum load, is found."

Meyer on Compression.—As compression has the greatest influence on the efficiency of a gas engine, Professor Meyer undertook a large number of experiments to test the effect of varying it. The first were made at Hanover, on an 8 H.P. horizontal Deutz-Otto engine driven by town gas, and having a cylinder diameter of 7·8 inches, stroke 11·8 inches. Normal number of revolutions 220 per minute. The piston worked between guides, having a special crosshead arrangement, so that the volume of the compression space could be varied by varying the length of the connecting-rod, and, in order still further to reduce the compression space, plates were fixed to the end of the piston. The charge was fired by a hot tube carefully adjusted to prevent premature or retarded ignition, whatever the degree of compression used. The quantity of gas admitted was regulated by a sliding cam, acted on by the governor according to the load on the brake. Thus the influence of variations in the composition of the charge was tested. The speed was varied in the usual way. The gas and air were measured through meters, the air being blown in by a fan; in the later experiments the fan was dispensed with. The temperature of the cooling water was taken in and out; that of the exhaust gases was determined by a Le Chatelier pyrometer.

Table No. 3 at the end of the book gives a summary of twelve of these interesting experiments, arranged in order of merit of heat efficiency per

B.H.P., by the author, and showing that the higher the compression of the charge the higher the heat efficiency. This varied from a maximum of 19½ per cent. to a minimum of 13 per cent. per B.H.P. In other words, the best results show that of the heat given to the engine, one-fifth was turned into useful power at the end of the crank shaft. As a series these experiments are very instructive, and the author was fortunately able, when at Hanover, to see the engine on which they were made.

Other later experiments with practically the same arrangements were carried out by Professor Meyer at Göttingen in 1899, to determine the difference in power of running an engine under the same working conditions with lighting and with power gas. They were made on a 10 H.P. Deutz engine with electric ignition; the moment of firing the charge could be retarded or anticipated at will. The gas producer was of the usual type with a boiler. In some of the tests the gases from the furnace were passed through a regenerator, and heated the air drawn in by the steam jet. Under these conditions the gases generated contained 8·8 per cent. more heat than when cold air was supplied, because the fuel (coke) yielded a larger quantity of gas per unit weight.

In the main trials the size of the compression space was varied as before, the total cylinder volume being successively 3·84, 4·59, and 4·98 times larger than that of the compression volume. At these different compressions the load and the ratio of air to gas were varied, other conditions remaining uniform. With lighting gas of 582 B.T.U. per cubic foot the consumption was 22·9 cubic feet per B.H.P hour with the highest compression, and 24·5 cubic feet with the lowest. With power gas of about 135 B.T.U. per cubic foot, the consumption was 106 cubic feet per B.H.P. hour with the highest, and 138 cubic feet with the lowest compression. All the data in these trials were most carefully worked out, and should be studied. A selection of eighteen, arranged on the same lines as the earlier tests, has been added at Table No. 3A.

The conclusions Professor Meyer draws from them are—Firstly, that the diminution in work done by the gases which is due to the heat lost to the cylinder walls and water jacket is relatively small, and is not much affected by the type of engine; secondly, that ignition should, as far as possible, be at the dead point; but if it falls a few degrees of the crank circle before or after, the work done will not be greatly influenced. Lastly, like other authorities, he repeats that the consumption of gas depends chiefly on the degree of compression, and the engineer can reduce it almost at will by increasing the compression, so long as pre-ignition is avoided. If, however, of two engines working at the same compression and same load, one shows a higher consumption of gas than the other, it must be attributed to imperfect combustion, the charge of gas and air not being so well mixed. "It is certain," he says, "that at

present, especially in engines driven with poor gas, large quantities of gas pass unburnt through the cylinder. The efficiency of many gas motors could be improved chiefly by avoiding the losses due to imperfect combustion, and by the exercise of greater care in mixing the fresh charge as it enters the cylinder."

Subsidiary experiments were made at the same time to determine the effect of varying the quantity of lubricating oil. It was found that the higher the temperature of the walls, the larger the quantity of oil passing to the cylinder, because more heat being developed, the oil became thinner, and flowed more readily, although the size of the orifice did not vary. The consumption of gas (and therefore of heat units) per I.H.P. was scarcely affected by profuse lubrication, but per B.H.P. it was much lower. Professor Meyer considers that both the consumption of lubricating oil and the temperature of the walls have a marked effect on the consumption of gas per B.H.P., although the indicated heat efficiency may be the same. If too much lubricating oil is supplied, it probably burns with the gas.

An important part of these experiments consisted in tests made under Professor Meyer's direction on the composition of the exhaust gases, to determine from them whether combustion were completed in the cylinder. The constituents of the gases were absorbed by successive reagents, and the gases weighed before and after; they were also burnt in a platinum capillary tube. They were drawn off in a vacuum immediately behind the exhaust valve, the utmost care being taken to obtain representative samples. The composition of the lighting and power gas was also determined. From a large number of samples, Professor Meyer concludes that in the engine tested with lighting gas, from 3 to 5 per cent. of all the heat given to the engine was, at normal load, lost by imperfect combustion, and passed out at exhaust; at about half-load the loss was increased to 15 per cent. With power gas the composition of the exhaust gases was much less uniform; at about three-quarter load they showed a loss of heat due to imperfect combustion of 13 per cent.

These trials mark an initial stage in that thorough study of gas engines, which is needed to determine the best degree of compression with a given ratio of air to gas, and a uniform speed, on an engine of given size, type, and power. The object of all experiments should be to fix the conditions for obtaining from any engine the maximum of work on the brake per unit of heat supplied in the gas. The ratio of air to gas must vary with the heating value of the gas, which differs greatly in various towns and places.

Mr. Dugald Clerk has devoted many years of study to the subject of combustion in a gas engine, and is one of the leading authorities on its theoretical as well as practical aspects. The theory of internal com-

bustion motors rests ultimately on a knowledge of the amount of heat converted into work. In a valuable paper* lately (1904) contributed by Mr. Clerk, he has, to elucidate the subject, drawn up a table which should be contrasted with the one given at p. 313. In this later table nine typical engines are compared, from a small Deutz engine tested by Slaby in 1882 to the large Cockerill tested by Witz in 1900, and a Crossley by Humphrey. The heat turned into indicated work rose in these trials from 16 per cent. in the earliest to 28 and over 30 per cent. in the latest; the heat lost to the jacket water fell from 51 to 24·2 per cent., while the heat rejected in the exhaust gases rose from 31 to 48 per cent. In the large single cylinder Cockerill engine the heat turned into indicated work was 28 per cent., heat lost to the jacket 52 per cent., heat rejected in the exhaust gases 20 per cent., showing practically the same percentage of heat given up to the walls as in the earlier engines, but a large gain in indicated work, due to the smaller quantity of heat discharged at exhaust.

To understand the reason for this gain in efficiency, a closer knowledge of the properties of the gaseous charge is required. Taking as a standard an imaginary engine worked with pure air, and assuming that its specific heat does not vary with the changes in temperature, Mr. Clerk calculates the efficiencies to be obtained by varying the compression space from one-half to one-hundredth the cylinder volume. In the first case the ideal efficiency works out at 24 per cent., and with a compression to one-tenth the original volume it rises to 61 per cent. In actual engines working with a temperature range of, say, 1,000° C. and 1,600° C. to 100° C. and 0° C., the loss in efficiency with the highest compression is 76 per cent. as compared with the ideal engine. This is probably partly accounted for by the still obscure question of variation in the ratios, at high temperatures, of specific heat at constant volume and at constant pressure. At p. 273 this ratio is given as 1·4, but in modern engines it is more often 1·3, and sometimes falls even lower. The reason for this is that, in modern engines, the whole of the heat is not evolved at the moment of ignition, but is apparently added during the forward stroke, causing the expansion curve to fall more slowly than if it were a pure adiabatic. Whether this phenomenon is due to an increase in the specific heat at high temperatures, both of air, and of the gaseous charge in the cylinder, is still doubtful. According to Mr. Clerk it is necessary to assume either that the specific heat is constant, and combustion continues during the expansion stroke, or that combustion is instantaneous, and the specific heat varies; either would cause the actual to fall below the ideal efficiency. "That heat is added," he

* Clerk on "Internal Combustion Motors," "James Forrest" Lecture, *Min. Proc. Inst. C. Eng.*, vol. clvii., Part iv.

says, "during expansion in many cases does not seem to be open to doubt; but how much heat is added depends upon a knowledge of the chemical history of the working fluid within a period, in a large engine, of about $\frac{1}{8}$ second, and in a small motor-car petrol engine within a period of $\frac{1}{30}$ to $\frac{1}{50}$ second."

From the two series of experiments made by Professor Meyer in Germany and Professor Burstall in England Mr. Clerk draws up useful tables, showing the deviations in the actual efficiencies from his theoretical air standard efficiency. In Professor Meyer's earlier tests the decrease was 58 per cent., in Professor Burstall's it varied from 38 to 59 per cent. It should also be noted that the character of the working agent undergoes a change, one set of chemical substances being transformed into another by the process of combustion, and therefore, in Mr. Clerk's opinion, their specific heats must also vary. Former experiments having, however, proved that the expansion curve falls—that is, the gases are cooled—more rapidly in the case of a rich than of a weak mixture, Mr. Clerk maintains that heat is added during expansion in some other way than can be accounted for solely by the change of specific heat. Not only do different gaseous mixtures cool at different rates, they also show an increase or contraction in volume. A mixture of two volumes of alcohol and six volumes of oxygen produced by combustion four volumes CO_2 and six volumes H_2O, thus increasing one-fifth in volume. Acetylene, on the other hand, when mixed with one and a half times its volume of oxygen, is reduced one-seventh by combustion.

Pre-Ignition.—Mr. Clerk endorses the conclusions of other scientific men that the smaller the compression space, or the higher the compression of the charge, the greater the efficiency obtained. The effect of this in large gas engines, however, as already shown, is frequently to cause premature ignition. It is still doubtful to what extent the gaseous mixtures now used in an engine cylinder may be safely compressed, without being fired before the dead point. In oil engines the density of the charge does not affect the question to the same extent, since both petrol and alcohol will bear a higher compression than heavy oils. Various methods of overcoming the difficulty of pre-ignition have been adopted, such as the scavenger charge of air, water injections (see the Bánki engine) and the compression of air only, as in the Diesel.

The injection of water into the cylinder before ignition has received comparatively little attention in England. One writer considers* that it is likely to become of importance in the future, although the idea is no longer held that, by being converted into steam, it increases the power. The higher efficiencies now obtained in gas engines have been the result of increased compression, and among other methods of rendering these

* *The Engineer*, Oct. 9, 1903.

higher compressions possible must be reckoned the admission of water into the cylinder. The practical utility of it in raising the limit of compression, and hence the thermal efficiency, has been demonstrated in the Bánki and in several alcohol engines. The water vapour generated probably acts by diluting, and by retarding the rise in temperature of the explosive mixture. To show its effect in an engine automatically fired, the writer suggests that a plate be fastened to the back of the piston in such a way as to reduce the capacity of the compression chamber. Premature ignition will then occur, but if water be injected at each stroke, and the quantity regulated, the moment of ignition can be controlled, and either retarded or advanced.

Professor Meyer is of opinion that pre-ignition may be caused by some foreign substance, such as caked oil, asbestos, or even by a part of the cylinder not sufficiently within reach of the water cooling. Possibly also, part of the charge left in the passages burns so slowly that it is not wholly burnt when the new charge enters. If these causes of pre-ignition could be eliminated, higher compressions than are now usual might be employed. On the other hand, even if the cylinder walls be unduly cooled, this will not prevent complete combustion, if sufficient oxygen is present to burn with the gas. If the gas valve is opened so late during the admission stroke that the gas has not time to mix thoroughly with the air, and the flame to reach it, combustion will not be complete, and this imperfect mixing of the charge may be one reason for the phenomenon of heat evolved during the expansion stroke. It is of the utmost importance for complete combustion at the dead point, which both theory and experience have shown to be necessary, that the gas should, on its admission, find sufficient air in its immediate vicinity to burn with it. Professor Meyer has himself observed the phenomenon mentioned by M. Petréano of a flame striking out of the exhaust valve when the exhaust pipe was taken off, and he attributes it mainly to particles of gas which had escaped combustion, and ignited on coming in contact with the outer air.

A new method of avoiding pre-ignition has been introduced by Mr. Clerk, consisting of the admission of a small charge of air at the end of the compression stroke. The effect of this arrangement is to reduce the flame temperature (or the temperature at the moment of ignition), which is always high in large gas engines, and to raise the mean pressure throughout the expansion stroke. The air serves to increase the volume and pressure of the charge, and to diminish its temperature and inflammability. Upon a "National" engine designed on these lines (see p. 119) Mr. Clerk has made exhaustive experiments, both air and cooled exhaust products being admitted to produce an additional artificial pressure of one atmosphere in the cylinder. By this means he increased

the indicated thermal efficiency of the engine from 28·7 to 34·4 per cent., and improved the brake efficiency from 25 to 27·5 per cent. The flame temperature was at the same time reduced from about 1,700° C. to 1,200° C., and the mean pressure increased from 89 to 110 lbs. per sq. inch. These results appear to show that engineers should direct their efforts to reducing instead of neutralising the actual flame temperatures, while increasing the pressures. There is still considerable difficulty in determining both the flame and what is known as the "suction" temperature of the charge in the cylinder.

Useful experiments on the temperature of the cylinder walls have been made by Herr Koerting.* The jacket of an engine was pierced in three places by holes penetrating to the inner cylinder wall, which were filled with mercury, and thermometers plunged into them; thus the temperatures in the cylinder at varying loads were known. The engine tested was a Koerting two-cycle. One hole was pierced in the exhaust ports in the centre of the cylinder, the second at the end of the cylinder, and the third between them. The temperatures, taken every quarter of an hour to half an hour, were:—In the exhaust port, at one-quarter load 156° C., at full load 170° C.; at the end of the cylinder, at one-quarter load 75° C., at full load 94° C.; in the intermediate hole, at one-quarter load 57° C., at full load 63° C. Koerting considered that the temperatures in the compression space are probably much higher than these, but less difficult to deal with, because expansion is amply allowed for.†

Wall Action in Gas-Engine Cylinders.—All these researches tend to show that the causes of loss of heat, and consequent waste of heat energy, depend largely upon the total internal area of the cylinder exposed to the gaseous mixture. The less this area for a given cylinder volume, the higher will be the pressure. Therefore the more the action of the walls can be diminished during the development of the heat, the more certain and rapid will be the explosion, and the greater the pressure of the gas. This result can be obtained in three ways, by reducing—

1. The time during which the wall action continues.
2. Its intensity.
3. The proportion of area of the walls to volume of the gases.

1. Opinions vary greatly as to the advantage of high piston speeds in gas engines, but the tendency of modern engineers is, in the main, to increase speed within reasonable limits. Beyond about 300 revolutions

* *Zeitschrift des Vereines deutscher Ingénieure*, 1902, p. 127.

† A series of interesting articles on the calculation of the work of a gas engine from the indicator diagram, in the same way as that of a steam engine, will be found in *Zeitschrift des Vereines deutscher Ingénieure*, 1901, p. 1640; and 1902, pp. 84, 606.

per minute, M. Richard considers that the friction and heat developed are too great to work an engine continuously, and if much heat is generated by explosion, a correspondingly large amount is discharged at exhaust. Within certain limits, however, high speeds are advantageous, because the colder walls have less time to act upon the hotter gases, and carry off their heat. The rapid expansion so much insisted on by Professor Witz has the same effect in diminishing the wall action, but it does not always mean a proportionate utilisation of the heat supplied to the engine. The Society of Arts' Trials show that in the Atkinson engine, in which expansion was greatest in proportion to admission and compression, the heat carried off by the walls—that is, during the expansion stroke—was relatively small, but more was discharged to the exhaust than in engines having less expansion. If the two items of heat expenditure be added together (see Table, p. 313), they will be found almost the same as in the Otto engine tested at the same time.

2. To diminish this great action of the walls, and to equalise their temperature and that of the gases, it is necessary to raise the temperature of the one, or lower that of the other. To raise the temperature of the walls is impossible, without injury to the engine. But by diluting the charge of gas with air to the limit of inflammability, and by utilising the inert gases, the heat of explosion may be diminished, without affecting the efficiency of the engine. This diminution of the maximum temperature is the reason of the comparatively high efficiency obtained in practice, with engines having combustion at constant pressure. As there is no very sudden rise in temperature, less heat is carried off by the walls, and more remains to do work on the piston.

3. The third is perhaps the greatest source of waste of heat in an engine cylinder. The most effectual method of diminishing the wall action is by previous compression of the charge, and the numerous experiments already quoted show that it is the chief means of increasing the thermal efficiency.

Loss of Heat.—In considering the losses of heat in an actual, as compared with an ideal, engine, Professor Meyer attributes the variations in the diagram of pressures, and thus in the area of work shown in an Otto engine, to the degree of compression, the chemical composition and heating value of the combustible, and the proportion in which the latter is mixed with air and with the products of combustion.* The losses of heat and energy during a cycle he gives as follows :—

(*a*) Loss of heat during admission and exhaust, due to back pressure, and shown as negative work in the diagram.

* Professor Meyer's excellent dissertations on the exchanges of heat during a gas engine cycle should be carefully studied in the *Zeitschrift des Vereines deutscher Ingénieure*, 1899, Nos. 11, 12, and 13, and in his *Untersuchungen am Gas-Motor*, 1903.

(*b*) Loss of heat during admission, with no diminution in the area of work, but only a decrease of temperature at the beginning of compression. If the gas in an engine cylinder were a perfect gas, the work done by it would depend entirely on the degree of compression, and not on the initial temperature. But owing probably to the increase of specific heat, the amount of the charge drawn in per stroke and the work done diminish slightly with an increase in the initial temperature, compression and all other conditions being the same. The lower this temperature at the beginning of compression, the less will be the loss of heat to the walls throughout the cycle.

(*c*) Loss or diminution of work due to the heat carried off during compression.

(*d*) Loss of work due to incomplete combustion and retarded ignition.

(*e*) Loss of work during expansion. It is these losses during compression and expansion which constitute the main loss during the cycle, and have chiefly to be considered.

However carefully an engine may be designed, to keep the temperature and pressure of the charge within practical limits, all authorities are agreed that the greater part of the heat in a gas motor is lost by radiation and conduction, or discharged at exhaust. In the heat accounts of the four engines given at p. 313, the jacket water and the exhaust carried off between them from 65 to 75 per cent. of the total heat developed. In the opinion of so competent an authority as M. Richard this waste cannot, in our present state of knowledge, be avoided to any great extent. The heat economised from the one is usually wasted to the other.

Variations in Expansion Curve.—The Otto diagram at p. 309 shows a peculiarity in the pressures obtained, which has hitherto not been satisfactorily explained. The fall of the expansion curve in the theoretical is, as we have said, more rapid than in an actual diagram. This theoretical curve represents exactly the fall in pressure, and therefore in temperature, which would be obtained, if the gases expended their heat entirely in doing work. If the curve of the actual diagram is flatter, and does not fall so rapidly, this difference shows that the pressure does not in practice sink so quickly, and heat is not parted with as speedily as in theory. The law of the mechanical equivalent proves that the amount of heat expended in doing work does not vary, but is always the same, in practice as in theory. If, therefore, the pressure and temperature do not fall so rapidly in an actual engine, heat is added in some way. This addition of heat is obtained either from within or from without. Most authorities maintain that it is evolved from the mixture itself, because the walls of the cylinder, cooled by the water

jacket, must always be at a lower temperature than the gases they enclose, and cannot convey heat to them. The moment of maximum explosion or pressure does not always agree with that of complete combustion. The gases may reach their maximum pressure, and the particles be driven widely apart by the flame spreading through them, before their perfect combination with the oxygen of the air, and reconstitution as CO_2 (carbon dioxide) and H_2O (water vapour). This is the phenomenon which is now known to take place in the cylinder of a gas engine, and to cause the addition of heat shown in the slow fall of the expansion curve. It is generally admitted that an "equilibrium of heat," as it has been called, occurs in almost all direct-acting engines, with explosion at constant volume. Heat is suppressed at the maximum temperature of explosion, to be evolved afterwards, during the expansion stroke. So much heat is carried off by the walls that there could be no approximation to adiabatic expansion, unless heat were in some way added, to counteract the wall cooling effect. The phenomenon is described in German by the expressive term "nach brennen." In English it is called "slow combustion," but it would be more correct to term it "after combustion." Its causes and the extent to which it prevails are still uncertain. It has been pointed out by Professor Boulvin that this "after combustion" tends to disappear with the increased compression in modern engines. The diminution in size of the compression or explosion space has the effect of driving out more completely the products from the former charge, and it was these, in Professor Boulvin's opinion, which contributed most largely to produce the phenomenon. To account for it, and for the rise in the expansion curve, the following theories have been advanced.

Stratification.—The first was put forward by Otto, because it was in the diagrams of his engines that the effect of this "after combustion" upon the expansion curve was first studied. He claimed it as a direct result of the stratification of the charge, one of the improvements specified in his patent of 1876. Instead of admitting the gas and air together through valves, as in later engines, the admission ports of the Otto were so arranged, that the air entered first. The gas valve then slowly opened, and the air was diluted with gas, the mixture increasing in percentage of gas as it continued to enter the cylinder until, the air port closing, nothing but gas was finally admitted. The products of combustion were not expelled from the cylinder, but remained and combined with the air in front of the fresh charge, to form a sort of cushion between the richer mixture and the piston, and to deaden the shock of the explosion. Trials were made by Professors Schöttler, Teichmann, Lewicki, and others, to determine whether stratification of the charge actually existed or not, but the theory has now been more

or less abandoned. Most of the latest authorities on the subject consider that stratification cannot be maintained, even if the gases enter the cylinder in successive layers of richness, because of the compressive and mixing power exerted by the back stroke of the piston. A certain degree of stratification of the charge is, however, claimed for several modern engines.

The increased economy obtained with the "scavenging" method appears effectually to refute the theory that stratification of the charge, and retention of the products of combustion, add to the efficiency of a gas engine. It is true that these inert gases heat the incoming charge, but their effect is distinctly injurious, and probably contributes to the premature ignition which is so troublesome in large motors. Mr. W. Beaumont is of opinion that, "even with comparatively small engines, the complete discharge of residual products, and the perfect mixing of the gas and air, have already done more for economy" than any other improvement. According to Professor Burstall (see Second Report, Gas Engine Research Committee), a scavenging charge is desirable, because a larger volume of fresh charge can be drawn in, if the cylinder is previously cleansed; but the value of the method diminishes with increased compression. In Table No. 1 will be found some interesting experiments on this type of engine, showing the economy obtained. The scavenging arrangements adopted in the latest Premier and Koerting engines, and in the Oechelhaueser also prove the same. In a valuable paper on "Recent Developments in Gas Engines," read before the Institution of Civil Engineers, January 28, 1896, Mr. Dugald Clerk discusses the causes of greater economy in modern engines. Of these the chief is compression, more compression meaning more, and less compression less economy. He also considers it essential to diminish the volume of the ports and clearance, and especially to reduce their surfaces to a minimum, in order to lessen the weight of metal heated and cooled per motor stroke. In modern gas engines the dimensions of the clearance volumes and surfaces have gradually decreased year by year. It should not be forgotten that the best standard of comparison between different gas engines is the thermal efficiency, and in calculating it the B.H.P. should always be taken, in preference to the I.H.P., to estimate the work done. (See tables at end of book.)

Dissociation.—The next theory to account for the phenomenon of "after combustion," or of development of heat during the expansion stroke, has been advanced by Mr. Clerk. He attributes it to the chemical action known as "dissociation." At certain high temperatures chemical compounds decompose, or separate into their constituent elements, and do not recombine until the temperature has fallen. Thus heat, which is one of the great forces in combining chemical elements,

is also a powerful agency in splitting up compounds. The existence of this phenomenon has been repeatedly verified. Without it, it would be possible, during the combustion of gases, to reach much higher temperatures than have ever been attained in practice. If, for instance, steam be raised to a very high temperature, it is decomposed into its elements of oxygen and hydrogen. The higher the temperature, the more complete the dissociation, until a point is reached, above which all gases exist only as primary elements. The temperatures of compound gases, therefore, are probably limited, though the extent of this limitation has not yet been determined. Without dissociation it should be possible in theory to raise the temperature of hydrogen burning in oxygen to 9,000° C., but no experiments have, to the author's knowledge, been made, in which a temperature of 3,800° C. has been exceeded. Clerk maintains that at the temperatures produced in a gas engine dissociation takes place, and checks the further development of heat, and this opinion is shared by Professors Ayrton and Perry. The gases decompose, their heat is suppressed, and not evolved until, the temperature being lowered by expansion, the chemical elements are able to recombine. If dissociation existed in the cylinder of a gas engine, its action would be as described by Mr. Clerk. Most scientific men, however, are now agreed that the estimate of temperature on which the theory is based is incorrect. Professor Schöttler also points out that, if dissociation really took place, there would be a sudden variation in the course of the expansion curve, because the law of expansion itself changes, whereas the changes in pressure are quite gradual.

Cooling Action of Walls.—Professor Witz has advanced another theory, and supports his view with the weight of his scientific reputation and experience. He attributes the variation of temperature shown in the slow fall of the expansion curve, and the suppression and retarded evolution of heat, entirely to the cooling action of the cylinder walls. To this he refers all the phenomena hitherto obscure in the cylinder of a gas engine. He is of opinion that this cooling effect has been neglected hitherto, and that, next to the charge itself, the walls play the most important part in the cycle of an engine. By carrying off the heat generated at the moment of explosion, they instantly diminish the temperature. Although continually cooled by the jacket, they act as reservoirs, and actually restore to the gas, during the latter part of the stroke, some of the heat they had previously absorbed.* In the earlier gas engines, without compression or ignition at the dead point, and with a much smaller range of temperature, the effect of the walls, though

* The opinions of Professor Witz here given touch, in the author's opinion, upon debatable ground.

ignored, was very great. In modern engines this effect is greatly restricted, with the result, according to Witz, that the walls are able to refund heat to the gas during the expansion stroke.

Increase of Specific Heats.—A fourth solution of the problem has been suggested by MM. Mallard and Le Chatelier. From various experiments they have made, they are of opinion that the specific heats of gases increase at very high temperatures, and that this increase may in part account for "after combustion." The subject is still in the stage of investigation, and no positive determinations have yet been made, although it has engaged the attention of several scientific men, especially of Mr. Dugald Clerk and Professor Meyer. Mr. Clerk's studies in this abstruse subject have been already mentioned (see p. 336). Professor Boulvin agrees with him, and says that the increase of specific heat in the gases at high temperatures has been proved by MM. Mallard and Le Chatelier. The ratio $\frac{C}{c}$ (specific heat at constant volume and at constant pressure) is less even than 1·3 at the highest temperatures realised in the cylinders of gas engines (see pp. 273, 336).

A valuable contribution to the subject has been made by Professor Meyer, who considers that an accurate knowledge of the specific heats of gases is of great importance in studying the theory of the gas engine. He argues the existence of the increase in this heat from the analysis of the exhaust gases. Taking an example from one of his own experiments, in which 43 per cent. of the heat was given up to the jacket water—*i.e.*, to the walls—the analysis of the combustible gases in the exhaust showed that only 4 per cent. of the total heat of combustion passed undeveloped through the cylinder. The indicator diagram showed that not more than 10 per cent. of the heat was yielded to the walls at the moment of "visible combustion" (explosion). If the specific heats of the gases are assumed to be uniform at all temperatures, the remaining large percentage can only be accounted for by very considerable "after burning" of the charge.* Such a great development of heat by combustion, after the maximum temperature of the stroke has been attained, appears to Professor Meyer improbable. Some variation in the specific heats must be assumed, though he does not think they increase so rapidly with the temperatures as has been supposed. Whatever their rate of increase, if it can be shown to exist, the old assumption that the heat should be added at the highest temperature will no longer hold good, but it will still apply for the temperatures generally attained in a gas engine. His researches are summed up in these words. "If the specific heats of the gases are independent of the temperatures, the degree of compression alone, and not the ratio of gas to air, apart

* Meyer, *Untersuchungen am Gas Motor*, p. 72.

from the slight variation it produces in the ratio $\frac{C}{c}$, have an influence on the consumption of gas. But if the specific heats vary with the temperatures, the effect of the ratio of gas to air is almost as great on the consumption as that of the degree of compression."

Whatever the causes producing the phenomenon of suppressed heat, there can be no doubt that it is in itself injurious, because, although ultimately developed, it is not evolved at the right time, and therefore cannot contribute to the maximum pressure of explosion. The difficulties of the subject have been ably summed up by M. Richard in the following words :—"No satisfactory answer has yet been found to the question: What is the cause of the loss of heat during explosion and expansion? It cannot be denied that it is partly caused by the action of the walls; they have an influence which, if studied alone, may almost be formulated as a law. But is the effect of the walls varying or constant? To what extent does it intervene, during the motor stroke, in the other phenomena? These are—the increase of specific heat at the temperature of explosion (not yet universally admitted); dissociation, a phenomenon rather suspected than proved; combustion continuing during expansion, which some deny and others vehemently affirm. If it exists, as in my opinion it does, it is a result of the composition of the charge, compression, and the method of ignition.. In a word, it is a most complex phenomenon, not only in itself, but because it is connected with all the actions simultaneously produced during the short period of a motor stroke."

Even with the help of the Entropy diagram we cannot, Professor Schöttler says, determine with absolute accuracy the movements of all the heat passing into an engine cylinder. It can only represent the heat which, during the part of the cycle under consideration, is communicated to the working agent. If for instance a certain portion of this heat is transferred, as soon as it is generated, by radiation to the walls and thence to the cooling water, it will not appear in the diagram. Only the difference between this heat and that developed by explosion and utilised in the cycle will be shown as heat received, and the same applies to heat lost in this way at any point of the stroke, although it has an important effect on the cycle. During combustion there is a great rise in temperature which is rapidly communicated to the cooler walls, and certainly less heat reaches the gases of combustion than is developed, or corresponds to the heating value of the gas. Under this head it should be noted that Mr. Dugald Clerk raised the temperature of the cooling water from 17° to 96° F., and claimed to obtain thereby an economy of gas of 10 per cent.

The author was of opinion that the cylinder wall action in gas, as in steam engines, is very considerable, and it may be well to compare this

action in the two types of motors. In the case of a single-acting horizontal four-cycle gas engine with water jacket, the difference of temperature between the gas and the metal is greater than that between the steam and the metal in a steam engine. In gas engines heat goes through the metal walls nearly always in one direction, from the centre of the cylinder outwards. There is a greater flow of heat at the explosion end of the cylinder and in the large clearance areas, because the temperature and pressure are greater than at the other non-explosion end. During the three non-motor strokes, the heat would travel through the walls much less rapidly, and the temperature of the metal would tend to become uniform. In a steam engine the wall action fluctuates periodically in the thickness of the metal, first in one direction, then in the other. During the steam stroke, heat passes from the hot steam to the cooler walls, and during the exhaust, from the hotter walls in the reverse direction.

In a gas engine, during the explosion and expansion stroke, the heat doubtless passes rapidly from the hot gases to the cooler walls, which, on the side touched by the water, are at a temperature of, say, about 150° to 180° F. The temperature of the gases will vary from, say, 1,800° to 2,500° F. If we assume an average of 2,000° F., there will be a difference of temperature of about 2,000° - 150° = 1,850° F. between the gases and the metal next the water, causing the heat to flow through the walls to the cooler circulating water.

During the exhaust stroke the gases are still much hotter than the walls, and the heat flow will be in the same direction, but less energetic. During the admission stroke of cold gas and air, the movement of heat will either be reversed or nearly suspended, as, by the time the charge has actually filled the hot cylinder and clearance, there will no doubt be little difference in temperature between it and the walls. During the compression stroke, there will be a tendency for the heat to pass again to the walls from the gases. We may thus assume that the flow of heat, though varying much in intensity, is generally from the internal to the external surfaces of the cast-iron walls, or from the hot gases to the cooler water.

At the explosion end of the cylinder the clearance surfaces will, to the thickness perhaps of a sheet of paper, approximate to the temperature of the dry gases. The lubricating oil will act as a non-conducting film, and tend to check the flow of heat. Nor must it be forgotten that, according to the opinion of the best authorities, the centre of the charge is much hotter than the parts in contact with the walls. The flow of heat may, therefore, commence from a hot nucleus in the middle of the cylinder. The thickness of the metal walls will vary, say, in different sized engine cylinders, from 1 to 1½ inches. As the metal at the

explosion end will be much hotter than at the other end, there will probably be a flow of heat horizontally through the thickness of the wall towards the crank, as well as the flow radially from the hot gases. These two movements of heat will probably form a thermal gradient slightly inclined to the axis of the cylinder.

Effect of Time.—Again, there is the question of time influencing the wall heat action. Taking two motors running at different revolutions per minute, the engine with the slower piston speed will give the water and the gases more time per stroke to interchange their heat, than the quicker running engine, in which a shorter time is allowed. Count should also be taken of the varying area of the walls exposed to the hot gases, by being uncovered by the piston during its out stroke. The quantity and speed of jacket water passing per minute round the cylinder, to cool so many square feet of internal surface, is another factor of this complicated wall action. In other words, the number of lbs. of water passing per minute through the jacket per square foot of internal surface should always be considered, as well as the action of the metal of the piston. As the clearance area exposed to the hot gases is much larger in gas than in steam engines, these important surfaces should, in accurate experiments, be given in square feet, as well as the cylinder volume. During the different strokes violent movements will take place inside the cylinder, particularly during the explosion stroke, when the whole cylinder is probably filled with flame.

On the other hand, as Professor Schöttler points out, the effect of a high piston speed must be to increase the amount of burnt products remaining in the cylinder after each explosion. Since there are more of these, less of the fresh charge can be admitted per stroke, and the mixture will be more diluted. This will have a consequent effect upon the ignition. As the charge is weaker, containing less gas, combustion will be less instantaneous, and spread less rapidly. Therefore, in high-speed engines, or when the normal speed of any engine is increased, care should be taken to make the ignition act more powerfully. Thus a higher speed increases the wall action in a cylinder, because, there being less of the fresh charge to heat, its effect upon this smaller quantity will be the greater. If, as Professor Witz says, the higher speed of an engine diminishes the time during which wall action takes place, this is counterbalanced by the more powerful action of the walls during that shorter time. The higher speed raises the temperature of the walls, but at the same time it also raises the lower limit of temperature. This is especially the case in the ordinary four-cycle engine, where a large quantity of inert gases is left in the cylinder, and hence the efficiency diminishes.*

* These views, although laid down in 1900, clearly indicate the lines on which modern gas-engine experiments have proceeded.

PART II.

PETROLEUM ENGINES.

CHAPTER XVII.

THE DISCOVERY, UTILISATION, AND PROPERTIES OF OIL.*

CONTENTS.—Petroleum: Its Production in Russia, America, and Scotland—Composition of Oil—Distillation—Density—Flashing Point—Heating Value of Oil—Professor Robinson's Experiments—Evaporation of Oil—Pressure—Utilisation of Oil—As Liquid Fuel on Railways—Advantages and Difficulties—Holden's Oil Burning Apparatus—Petroleum for Marine Purposes—Oil Gas—Mansfield Producer—Keith—Pintsch—Kemp-Welch.

THE name petroleum, or rock oil, is derived from the Latin words *petra*, a rock, and *oleum*, oil. It is a mineral product, obtained from the earth in two different ways. Most of the oil used is drawn, at varying depths, from subterranean wells in a natural state, but a relatively small quantity is also produced by distillation from bituminous shale. The extraction of oil has been carried on in Scotland since 1850; the discovery of rock oil in the earth, and the operations necessary for bringing it to the surface, date from a few years later. A third kind of oil, which must be distinguished from these, is obtained from fat and grease, by the application of intense heat in retorts. The process is usually continued until the oil has been converted into a rich gas. Lastly, there are vegetable oils, such as linseed, castor, palm, or olive oil, from which gas may also be produced by distillation. To distil gas from any kind of oil great heat is necessary.

Petroleum.—Within the last quarter of a century petroleum has become a most important article of commerce. There are two countries from which this oil has hitherto been chiefly obtained, the shores of the Caspian Sea, and the centre of the United States. It is known, however, to exist in many other places, and has been found in South America, especially in Peru and the Argentine Republic, Canada, India, Assam, Borneo, Java, Beluchistan, Japan, China, Burmah, Egypt,

* Students desirous of investigating this important subject with special reference to the geographical and geological distribution of petroleum throughout the world, its refining, characteristics, uses and testing, are referred to Sir Boverton Redwood's valuable work on *Petroleum*. (Griffin & Co.)

Australia, and in the south-east of Europe. Some scientific men are of opinion that petroleum may be discovered almost everywhere, if the borings are carried deep enough into the earth. But for the present the supply from Russia is, and will probably long continue to be, practically unlimited, and Russian petroleum is conveyed so cheaply all over Europe, that it is not worth while to seek for oil elsewhere. The chief centre of the oil industry is round the shores of the Caspian, though important oil fields have been discovered in Central Asia. It is only within the last half-century that these vast natural reservoirs have been utilised, and their discovery threatens in several ways to revolutionise commerce, especially as providing a new kind of fuel. The town of Baku, the capital of the Caspian district, has from a village become a large and flourishing city, since oil has been found in great quantities in its vicinity. The existence of an oil region round the Caspian was known from the earliest times. The district was called by the ancients the Fire Region, and the mysterious flames which issued from fissures in the rocks were worshipped by them 600 years B.C., as manifestations of the Fire God. These flames are nothing more than the gases given off by the subterranean oil reservoirs, ignited at some remote period, and which have never been extinguished.

Russian Oil.—The extraction of oil from the earth in the Baku district is carried out on a regular system. The wells are tapped, or the oil is "struck," as it is called, and immediately rises to the surface at a high pressure. It is then conveyed through pipes direct to the refineries, where it is purified, and separated into the lighter volatile oils, as naphtha, the lighting or intermediate oils, lubricating oils, which are all of varying density, and the crude petroleum called "astatki." Through another line of pipes it is next carried to fill the tanks in the steamers on the Caspian, no other method of distribution being employed. This system of pipes forms a network over an area of several square miles round Baku, and the oil issues from the wells at so high a pressure that no pumping is required, until the flow has begun to diminish. It is struck at a depth varying from 70 to 825 feet below the surface. A line of pipes has recently been constructed for carrying refined oil from Baku through the Caucasus to Batoum, on the Black Sea, 560 miles distant, from whence it is conveyed by sea to the south of Russia, and throughout the countries bordering on the Mediterranean. The oil industry of Baku has been greatly developed, and almost created by two Swedish engineers, Robert and Ludwig Nobel, who organised a system of obtaining and refining the oil, and distributing it all over Europe.

American Oil.—The second source of oil supply is from Pennsylvania and the Alleghany district in North America, and the newly discovered oil regions of Athabasca in Central Canada. Here also the

supply is ample, though the borings are carried much lower, oil being usually found at a depth of from 500 to 4,000 feet from the surface. The petroleum wells of Pennsylvania were discovered about 1859. The oil issues from the ground at a lower pressure than in the Caspian district, and is pumped through pipes, often hundreds of miles in length, to the chief commercial centres of the United States. There are about 25,000 petroleum wells in America, and 400 in the Caspian, but the supply in the latter is very much more abundant. In 1890 the yield of oil from the American wells was 2,600,000 gallons a day, and from the Caspian nearly 2,700,000 gallons per day. The supply from both is at present apparently unlimited, and there are only two drawbacks to the use of petroleum all over the world for lighting and heating purposes, &c. The first is the cost and difficulty of transport, which will no doubt be overcome; the second is the varying composition and inflammable nature of the oil, necessitating great care in carrying and storing it.

Scotch Oil.—The third source from whence mineral oil is obtained is by distillation from bituminous shale or "petroleum peat." Dr. James Young was the first to discover, in 1850, that petroleum could be extracted from shale, rich beds of which exist in abundance in Scotland. The oil produced is usually known as paraffin oil.

Thus during the last fifty years a vast and hitherto unsuspected store of natural fuel has been brought to light, which, unlike coal, requires no laborious mining process to extract it from the earth. It is merely necessary to bore a well of the requisite depth, with an instrument known as a well-driller, over which a wooden structure is erected, and the oil issues forth in a liquid stream. The boring is often now carried out by a motor driven by oil. Care must be taken, however, in the Caspian district, that the flow of oil is not allowed to become so great as to flood the country. Thus in the Droojba fountain, in 1883, the oil rose to a height of 300 feet, and flowed at the rate of 2,000,000 gallons a day. It burst to the surface with the force of a miniature volcano, carrying with it large quantities of sand, and the damage done to the surrounding country ruined the owners. About £10,000 worth of oil per day were thrown up, and most of it wasted. To check this tremendous flow, the wells are now "capped" at once if possible, and frequently covered over, or "corked," if the price of oil is at the time so low as to render the working unremunerative. Thus the supply is stored for future use.

Composition of Oil.—The difficulties of utilising Nature's bountiful stores of light and heat become apparent, as soon as the chemical constituents of the oil are considered. The composition of fuel such as coal, wood, &c., varies considerably, and with oil it is even less

uniform. Crude petroleum consists of various hydrocarbons, differing in their proportions in every oil, and all are of different densities. The density of some is very low, and they are much lighter than water (taken as unity). The lighter the more dangerous the oil, because the more rapidly it evaporates, giving off inflammable vapours which ignite if a light be brought near. As the chemical constituents of petroleum have different boiling points, they are vaporised at different temperatures. Hence the difficulty of dealing with these oils. At a low temperature the lightest and most volatile hydrocarbons rise to the surface, and are first given off. As the temperature increases, and more heat is applied, the heavier and more inflammable vapours are separated, till at last all the volatile oil is evaporated, and a thick heavy liquid is left, called "astatki" in Russia, and "residuum" in America. Formerly this petroleum refuse was considered useless, and thrown away. Both in America and Russia it was allowed at times to run to waste, and formed lakes of liquid petroleum, which were often set on fire to get rid of them, or carried off by pipes into the sea. It is now known that, though this refuse cannot be volatilised by the application of heat, however intense, it may be broken up or divided into spray and utilised, by injecting air or steam into it, and thus burning it. It is used extensively in Russia and America, and forms a valuable liquid fuel, though it hardly pays at present for the cost of transport to other countries.

Distillation.—If American, Russian, or Scotch shale oil be heated gradually in a retort, it is divided up by what is called "fractional distillation" as follows:—The highly inflammable vapours, variously known as naphtha, gazolene, benzoline, petrol essence, benzine, spirit, &c., are first given off.* These vapours, though very dangerous, are free from impurity. As the temperature of the retort increases, heavier gases are liberated, and carbon is deposited; while at a red heat the residuum is split up, or "cracked," and converted into a true oil gas, containing a large amount of tarry products. "Cracking" is the term applied to petroleum when, by subjecting it to great heat, the heavier chemical constituents, which will not themselves vaporise at that temperature, are split up and decomposed into lighter hydrocarbons, which are readily evaporated. The different oils thus formed are, in the order of their density, volatile essence or spirit; kerosene or illuminating oil; what is called intermediate oil, because in density and inflammability it is between the light and heavy oils; thick lubricating oils; and, lastly, *astatki* or refuse, which may either be made into gas, or, by the addition of superheated steam, burnt as fuel.

* Different names are given to these volatile oils and essences in different countries.

Different Densities of Oil.—It must not be supposed that these different classes of oil are ever rigidly defined in any petroleum. They pass one into the other, from lighter to heavier, by imperceptible gradations, and can only be correctly tabulated according to their density. Nor is even this an infallible test of their quality, for the same oil, naphtha, kerosene, or lubricating oil, will often vary in density, according to the petroleum from which it is obtained. Sometimes an oil will contain more of the lighter, sometimes more of the heavier constituents. At Baku the lightest oils are found in wells of great depth, and hence the high pressure of the oil fountains, and the force with which they rise; the heavier kinds lie nearer the surface. The difficulty caused by the varying density of petroleum, and the different temperatures at which it vaporises, is the main obstacle to its use in heat engines, and special means are nearly always employed to convert it into spray. If the oil be simply injected into the cylinder like gas, the heavy hydrocarbons are soon deposited, and are troublesome to get rid of. If only the lightest oils or spirit are used, they are even more easily ignited than gas, but are expensive, and dangerous to transport. Legally they can only be stored for heat motors with special precautions. The heavy liquid refuse is not inflammable, and therefore quite safe, but to employ it in an engine it must be previously distilled in a retort. It is the intermediate kinds of oil, obtained from heavy residuum after refining away the volatile essence, which are chiefly used for lighting and heating; and petroleum, as distinguished from spirit or naphtha, motors are usually driven by these oils only. If natural oils have been carefully refined, and their more volatile constituents drawn off by the application of heat, they become much less inflammable. Lighting oil or common kerosene will not ignite at the ordinary temperature, and will even extinguish a lighted taper when applied to it. Special legal restrictions are, however, placed on the use of oil in most European countries, and a test, known as the Flashing Point, is prescribed to determine its inflammability.

Flashing Point.—The flashing point of an oil is the temperature at which it gives off inflammable vapours, and depends chiefly on its more volatile constituents. Careful allowance must always be made for temperature in dealing with oil, because petroleum increases greatly in volume with every degree rise of heat. To determine its specific gravity, water is taken as unity, and the weights of oil as decimals. The higher the specific gravity of oil, or the more closely it approximates to the density of water, the less danger will there be of its inflammability. Petroleum which has a low specific gravity contains light chemical constituents, and these are very volatile, and are given off at a low temperature. Hence it catches fire more readily, and is often

more inflammable, than other oils of greater density, containing heavier hydrocarbons.

The flashing point of oil is usually determined by means of an apparatus designed by Sir F. Abel. A small cylindrical vessel of oil has a tight fitting cover with three holes, which can be opened or shut by means of a slide. A thermometer is fixed in the vessel, and a gas burner and flame are also provided. The oil is heated by raising the temperature of the water in the receiver by means of a lamp. At about 66° F., or 19° C., the slide in the cover of the air vessel is slowly withdrawn, the flame brought beneath the lid through the holes, and the oil watched until it lights or flashes. The flashing point is determined from the temperature of the oil. In most countries of Europe and America no oil giving off inflammable vapours—that is, having a flashing point below a certain limit of temperature, which is fixed by law—may be stored without a special licence. In England the limit is 73° F., or 22° C.; in France, 35° C.; Russia, 28° C.; Germany, 21° C.; Canada, 85° F. In America the legal limit varies much in the different States. The flashing point may also be roughly determined by holding a lighted taper above an open vessel filled with oil. As the temperature is raised by the heat of the taper, light hydrocarbons are liberated, rise to the surface and ignite, and if a thermometer be placed in the oil, the flashing point can be read off. The higher this temperature, which determines the limit of ignition, the safer is the oil to use.

TABLE OF CONSTITUENTS OF AMERICAN, RUSSIAN, AND SCOTCH SHALE OIL, WITH SPECIFIC GRAVITY AND FLASHING POINT (*Robinson*).

Constituents.	American Oil.		Russian Oil.		Scotch Shale Oil.		Flashing Point.
	Volume.	Specific Gravity.	Volume.	Specific Gravity.	Volume.	Specific Gravity.	
	Per cent.		Per cent.		Per cent.		Degrees C.
Benzine light oils, .	4	0·700	1	0·725	5	0·730	−10
Benzine heavy oils, .	2	0·730	3	0·775	...	...	0
Kerosene lighting oils, . . .	65	0·810	33	0·822	35	0·805	25 to 50
Intermediate, . .	...	...	10	0·858	5	0·850	105
Lubricating pyro-naphtha oils, .	18	0·880	38	0·903	15	0·885	110 to 200
Paraffin wax (vaseline), ...	2	0·90	...	0·925	12	0·90	...
Residuum and loss, .	8	...	15	...	28	...	...
	99		100		100		

Ignition Point.—The ignition or burning point of oil is the temperature at which the oil itself, and not the inflammable vapours given off,

takes fire. It is, of course, of greater importance to determine the flashing than the burning point, the former being reached long before the oil itself is raised to the ignition point. As the lowest legal flashing point of an oil in England is 73° F., naphtha or petroleum spirit, which ignites at a lower temperature and is very dangerous, may not be stored unless by special licence. The flashing point of astatki or crude petroleum refuse is above 200° C.; intermediate Scotch shale oil has a flashing point of 105° C. = 221° F.

The table on p. 354 (from Professor Robinson's *Gas and Petroleum Engines*) gives the proportions by volume, flashing point, and specific gravity of the different hydrocarbons contained in Russian, American, and Scotch petroleum.

The following table (from Redwood, see p. 356) shows the chemical constituents of the oils from different countries, and their heating value, &c.

Calorific Value of Oil as used in an Engine.—Mr. C. J. Wilson, F.S.C., one of the best London authorities on this subject, has made many determinations of the heating value of oils with his improved fuel calorimeter, especially in connection with the Royal Agricultural Society's and other tests.

The heating value of oil is now usually determined in a closed calorimeter, but in applying this determination to the combustion of oil in a motor cylinder, the conditions are very different. When oil is burnt by means of compressed oxygen in a calorimeter, the whole of the water produced by the combustion of the hydrogen is condensed to the liquid state, and cooled to the temperature at which the experiment is made. It is, therefore, necessary to know the amount of this water, and allow for the heat which would be required to evaporate it, since in all cases where an oil is used as fuel or power, the products escape in the gaseous state. The calculation is similar to that made to determine the higher and lower heating value of gas (see p. 291).

The following extract on the heat value of Russolene and Broxbourne oils, tested by Mr. Wilson, is taken from the Royal Agricultural Society's Report for 1894:—

"**Russolene Oil—Calorific Value.**—To determine this, the oil was completely burned in a closed bomb with compressed oxygen, and the heat produced carefully measured. Calculated to calories per gramme of oil, the mean of two concordant experiments is 11·055. This figure includes all heat obtained by condensation of produced water, and cooling this and the gaseous products to 28° C. In order to obtain a correction for the water produced by combustion, the percentage of hydrogen in the oil was determined, and found to be 14·05 per cent.; the produced water will, therefore, be 1·2645 times the weight of the oil.

TABLE OF COMPOSITION AND HEATING VALUE OF OILS (from *Redwood*).

Description and Locality of Oil.	Specific Gravity at 0° C.	Chemical Composition.			Lbs. of Water evaporated per lb. of Fuel from 100° C.	British Thermal Units, per lb.
		Carbon.	Hydrogen.	Oxygen.		
		Per cent.	Per cent.	Per cent.		
Heavy petroleum from West Virginia,	0·873	83·5	13·3	3·2	14·58	18,324
Light ,, ,,	0·841	84·3	14·1	1·6	14·55	18,401
Light petroleum from Pennsylvania,	0·816	82·0	14·8	3·2	14·05	17,933
Heavy ,, ,,	0·886	84·9	13·7	1·0	15·30	19,210
American petroleum,	0·820	83·4	14·7	1·9	14·14	17,588
Petroleum from Parma,	0·786	84·0	13·4	1·8	13·96	18,218
,, ,, Pechelbronn,	0·912	86·9	11·8	1·3	14·30	17,474
,, ,, ,,	0·892	85·7	12·0	2·3	14·48	18,036
,, ,, Schwabweiler,	0·861	86·2	13·3	0·5	15·36	18,824
,, ,, East Galicia,	0·870	82·2	12·1	5·7	14·23	18,153
,, ,, West Galicia,	0·885	85·3	12·6	2·1 (N.O.)	14·79	18,416
Shale oil from Ardèche, France,	0·911	80·3	11·5	8·2 (O.S.N.)	12·24	16,283
Coal tar from Paris Gas Works,	1·044	82·0	7·6	10·4	12·77	16,049
Petroleum from Balakhany,	0·882	87·4	12·5	0·1	...	21,060
Light petroleum from Baku,	0·884	86·3	13·6	0·1	16·40	20,628
Heavy ,, ,,	0·938	86·6	12·3	1·1	15·55	19,440
Petroleum residues from the Baku factories,	0·928	87·1	11·7	1·2	...	19,260
Petroleum from Java,	0·923	87·1	12·0	0·9	15·02	19,496
Heavy oil from Ogaio,	0·985	87·1	10·4	2·5	14·75	18,146

Taking the latent heat of water at 28° C., as 587 calories give 0·742 calorie per gramme, and deducting this from 11·055 give 10·313 calories as the heat of combustion of 1 gramme of the oil; products of combustion in the gaseous state at 28° C. This oil seems very constant in composition, for a sample examined more than a year ago gave 14·07 per cent. of hydrogen, and a calorific value of 10·3 calories per gramme—practically identical with the above.

"The heat value is, therefore, nearly 18,600 British T.U. per lb. Comparing this with Welsh steam coal, with a calorific value of 14,500 thermal units per lb., 1 lb. of oil will, in heating value, be equivalent to 1·28 lbs. of coal, and comparing it with London gas, having a calorific value of 19,200 British T.U. per lb., it would be equivalent to 0·97 lb. of gas. The specific gravity of this oil at 60° F. is 0·82, and flashing point (Abel test) 86° F."

"**Broxbourne Oil—Calorific Value.**—The mean of two experiments in the compressed oxygen calorimeter gives 11·019 calories per gramme, all produced water being condensed. The correction calculated from the hydrogen percentage is 0·742 calorie, giving as the heat value 10·277 calories per gramme, all products of combustion in the gaseous state at 24° C. This corresponds to a thermal value of 18,500 British T.U. per lb., the specific gravity of the oil at 60° F. being 0·81, and flashing point (Abel test) 155° F. The Broxbourne oil was about double the price of the Russolene."

Professor Robinson's Experiments.—A series of careful and interesting experiments were undertaken by Professor Robinson, to determine the nature of the changes produced by heat in different kinds of oil. In order to ascertain the properties of oil, and how much additional heat was necessary to convert it into a vapour before using it in the cylinder of an engine, he desired to know the temperature at which the oil distilled or evaporated, and the pressure of the petroleum vapour given off. The first point could only be determined by the process of frictional distillation. A glass flask filled with petroleum was placed in a sand bath, and slowly heated by the flame of a Bunsen burner. Two thermometers were used, one in the oil, the other at the neck of the flask. By this apparatus Professor Robinson was able to take the temperature of the oil, and of the vapour as it was given off; the latter was then passed through a glass tube surrounded with iced water into a graduated condenser. With water the boiling point would always be the same, but with oil it was necessary, as distillation ceased at one temperature, to increase it continually. The temperatures of the oil and vapour were found never to agree completely, but the higher the temperature of the oil, the less difference there was between it and the temperature of the distilled vapour. A marked difference between the

various oils tested was found, in the more or less gradual distillation of their constituents, and the percentage given off at the different temperatures. As a rule, Scotch shale oil distilled slowly at a high temperature, with the exception of Trinity or lighthouse oil, 55 per cent. of which distilled between 170° C. and 230° C. Some of the ordinary lubricating oils distilled rapidly at a temperature commencing at 120° C., the Russian at 130° C. The oils which distilled a large percentage of their volume within a limited range of temperature, showed a more or less uniform composition. Others evaporated slowly through a wide range, proving that they were more complex in composition, and made up of hydrocarbons having varying boiling points. Only a small percentage of the heavy, intermediate, and Scotch shale oils was distilled at a very high temperature. The range of temperature applied to these oils varied from 120° C. to 270° C. At a temperature of from 215° C. to 240° C., about 50 per cent. of the American and Russian oils distilled.

Evaporation of Oil.—The next experiments were undertaken to determine the evaporation from heavy oils in the open air, when exposed to a slow gentle heat, under ordinary atmospheric conditions, and thus the amount of light hydrocarbons they contained. Lighthouse, Scotch shale, and lubricating oils, having a specific gravity of 0·810 to 0·853, were placed in shallow receivers, and a steady heat maintained beneath them, the temperature of the oils being kept for three hours at from 40° C. to 65° C. The amount of evaporation was determined by weighing the oils before and after the experiments, and it was found that the percentage of loss varied inversely as their specific gravity. With the heaviest lubricating oil, the loss in weight was 2·96 per cent., with the lightest oil of 0·810 specific gravity it was 6·90 per cent. in the same time. These experiments show the degrees of safety with which oils may be stored in hot climates, and the necessity of ventilating the oil tanks and keeping them cool, thus diminishing risk and loss by evaporation.

Pressures of Oil.—Professor Robinson next endeavoured to determine the pressures of the different oils, corresponding with a given rise in temperature. Some difficulty was experienced in making these trials, because it was found much less easy to prevent leakage from the joints with petroleum vapour than with steam or lighting gas. The testing apparatus consisted of a U-shaped glass tube, having one limb longer than the other. At the end of the shorter was a spherical bulb, the longer was provided with a graduated scale. The tube and bulb were filled with mercury and oil, the oil being uppermost in the bulb. The temperature was raised by placing the glass apparatus in a glycerine bath, gradually heated by a Bunsen burner. As the sample of oil in the bulb increased in temperature, the pressure generated by its vapour

forced the mercury down the bulb and up the longer limb of the tube, and its rise was noted on the scale. Corrections were carefully made for the temperature of the room, latent heat of evaporation of the oil, expansion of the glass and mercury, &c. The height of the mercury in the tube showed the pressure attained by the petroleum vapour in the bulb, corresponding to the rise in temperature of the glycerine bath. The results of the experiments were afterwards plotted on curves, showing the proportional increase of pressure with increase of temperature, in the same way as with steam. Professor Robinson gives various curves exhibiting the temperatures and pressures for different oils. It was found that steam had a higher pressure at a given temperature than any of the oils, except petroleum spirit or naphtha, the pressure of which rises more rapidly in proportion to its temperature. At 300° F. the pressure of petroleum spirit was 125 lbs., and that of steam is 55 lbs. per square inch. The pressure of ordinary oils was much less. Common lighting oils, chiefly American, gave an absolute pressure of a little above 150 centimetres of mercury, at temperatures varying from 170° C. to 200° C., while the heavy oils, as Lighthouse or Scotch shale, having a specific gravity of about 0·825, showed a very low absolute pressure,* 90 to 94 centimetres of mercury at a temperature of 200° C. The lighter the oil, the more nearly it approached the temperature and pressure of steam. At lower temperatures the oils exhibited great differences of pressure, but at the lowest temperature tested, about 80° C., all gave nearly the same pressure—viz., about 80 centimetres of mercury (absolute pressure). At temperatures below 100° C., the pressure of water vapour was very much higher than that of any oil.

The pressure of air at a given temperature being known, it is possible, with the help of these valuable tables, to determine approximately the temperature and pressure of petroleum vapour, and therefore the work which should be obtained from a mixture of oil and air in the cylinder of an engine. Much, however, remains to be done, and at present we know little about the action of petroleum when subjected to considerable heat in a motor. The difficulties of the subject are increased by the complex constitution of oil. The latent heat of evaporation of petroleum is about one-ninth that of water—that is, the same quantity of heat will evaporate nine times as much oil of average specific gravity as water, but the expansion of the vapour is only one-fifth that of water vapour or steam. Hence the same quantity of heat will produce $\frac{9}{5}$ or 1·8 times as much oil vapour as steam from water. The above data are from Professor Robinson's able lectures at the Society of Arts on "The Uses of Petroleum in Prime Motors," to which the student is referred for an exhaustive treatment of the subject. Professor Robinson was the first, as

* Absolute pressure is 14·7 lbs. below the pressure of the atmosphere.

far as the author was aware, to make a special study of this difficult question.

Utilisation of Oil.—Having thus considered the chemical composition and properties of oil, it will be evident that, though it can be utilised in many ways to produce heat, the process is complicated, because its constituents vary so widely. There are four methods by which petroleum may be used to generate mechanical energy in a heat motor.

I. As liquid fuel it is burnt under a boiler to evaporate water. In this case the petroleum is simply used as fuel, and produces the same effect. It is injected through a nozzle, with an admixture of superheated steam and air, into the furnace, where it is burnt in the ordinary way. The heaviest petroleum and oil refuse may be thus employed to generate heat; the greater the specific gravity of the oil, the better suited it is for fuel.

II. Petroleum may be subjected to destructive distillation in a retort, and turned into a fixed gas, in the same way that lighting gas is distilled from coal. Any oil may be treated in this manner, but the best for distilling are the intermediate oils, which are neither so light that they escape before they can be gasified, nor so heavy that they cannot easily be broken up. The oil gas thus produced is exceedingly rich, having twice the heating value of coal gas. Mixed with air in proper proportions, this gas is introduced into the cylinder of an engine, and the force of the explosion drives the piston forward, as in a gas engine.

III. The lighter and more volatile constituents of petroleum, such as gazolene, benzine, petroleum spirit, essence or naphtha, are used in the same way as oil gas, to work a motor. The spirit is previously prepared, the heavier hydrocarbons withdrawn, and the power necessary to drive the engine is obtained by explosion, as in other internal combustion motors. Engines worked with these lighter oils and essences require a carburator of some kind, in which a suitable proportion of air is saturated with the inflammable spirit, generally by being passed over it, to form the charge.

IV.—Ordinary petroleum is evaporated at a moderate temperature in an apparatus contiguous to the engine, and, mixed with air, is used, like benzine or spirit, to drive the piston by the force of explosion. Here also the oil constitutes both the fuel and the working agent. Usually it is wholly vaporised, and burnt in the engine cylinder, but sometimes a heavy residuum is left.

Various Methods.—All these methods of utilising petroleum as fuel present difficulties, owing to the complex nature of the oil, except when it is evaporated as a pure spirit. It was long thought impossible to burn the heavy astatki, but when converted into spray by injecting steam or air into it, it can under certain circumstances be profitably employed.

When the petroleum is turned into a fixed gas, without the addition of air, difficulties arise, because the gas becomes laden with tarry products which, unless it is well washed and cooled, clog the pipes and valves. There is another obstacle when the lighter constituents of petroleum are utilised in an engine. These are given off at different temperatures, and the process is assisted if a large surface of the oil is brought in contact with the air. It is therefore agitated mechanically, the whole of the volatile constituents are gradually evaporated, and a heavy residuum remains, which is usually wasted. Most foreign inventors prefer to utilise only the lighter and more inflammable portions of the oil, and to sacrifice the remainder, thereby obtaining quicker evaporation, more power, and cleaner combustion than with heavier oils, though the consumption is greater. But the method more generally employed in oil engines in England, except for motor cars, is to evaporate the whole of the oil, and this requires the application of heat.

We will now consider—I. Petroleum as fuel, and II. Petroleum when converted into oil gas. In the next chapter we shall treat of III. The use of Petroleum spirit, and IV. Crude Petroleum in oil engines.

I. Petroleum as Fuel.—The advantages of petroleum, when burned as liquid fuel, are so great that it is safe to predict it will in time compete with coal and other fuels, and become an important factor in the commerce of the world. There are now a large number of "oil steamers" on the Caspian, in which the boilers are fired with astatki. All the locomotives on the Tsaritzin and Grazi Railway in south-east Russia are fitted with an apparatus for burning petroleum refuse, instead of coal, under their boilers. Coal in that part of Russia, being dear and scarce, the economy thus realised is considerable. In fact, the Baku oil fields have created the Caspian fleet. The uses to which petroleum is now being turned in Russia, where the oil is obtained on the spot, will doubtless be extended to other parts of Eastern Europe.

Difficulties.—The difficulties attached to the use of petroleum as fuel are—first, its complex constitution; secondly, its inflammable nature; and thirdly, its cost. The two first do not apply to astatki or petroleum refuse. The heavy oil used on the Russian railways is scarcely more inflammable than coal, and there is consequently no danger in using it. This was proved during an accident on the line, when an engine and carriages left the rails, and the tank of astatki in the tender did not ignite. The constitution of the petroleum is also fairly uniform, because all the volatile hydrocarbons have been evaporated, and though it is heavy and difficult to break up into spray, yet when combined with injections of steam and air it forms a safe and excellent combustible. At present, however, it can only be used in countries producing it, on

account of the cost of transport. In England it is not likely to compete with native coal, but it may in the future be found in large quantities in our Colonies and Dependencies, and used to advantage for locomotives and marine engines. The steamships of the Chilian Company use 100,000 tons of petroleum yearly. An abundant supply is found in Peru, and oil fields are also being opened up in Ecuador. In Scotland we have an almost unlimited quantity of shale, capable of yielding 120 gallons of oil per ton, but it is chiefly utilised at present for making gas, and for metallurgical and other processes.

Advantages.—The first advantage of using petroleum as fuel, whether under boilers or in the cylinder of an engine, is its purity. It contains no sulphur, and gives off little or no smoke. If the oil is perfectly consumed, petroleum is the cleanest of all fuel. Where the oil is used as liquid fuel to evaporate water, heat is economised because, as it passes automatically into the furnace from a tank, it is not necessary to open the fire door, and the temperature of the furnace is not lowered. Petroleum is also more convenient to store, and occupies less space than a corresponding quantity of coal. Lastly, it is of much greater heating value, as shown by the amount of water it evaporates per lb. of fuel. It has twice the evaporative power of some coal. Professor Robinson quotes figures to show that it evaporates at least 50 per cent. more steam than best Durham steam coal. Russian petroleum refuse burnt in a series of shallow troughs under ordinary boilers evaporated 14½ lbs. of water per lb. of refuse; coal burnt in the same boiler gave an evaporation of 7 to 8 lbs. water per lb. of coal. So high a result is not obtained when the astatki is sprayed. Professor Unwin tested the evaporative value of petroleum under a steam boiler, and found it to be 12·16 lbs. water (from and at 212° F.) per lb. of oil burned. The rate of evaporation was 0·75 lb. water per square foot of heating surface. He estimates the calorific value of the petroleum he used at about 25 per cent. higher than an equal weight of Welsh coal.

Liquid Fuel.—It is on the Russian South-Eastern Railway that the value of petroleum as fuel for evaporating steam in locomotives has been thoroughly tested. Mr. Urquhart, the able superintendent of the line, has by degrees replaced coal by petroleum in almost all the engines under his charge. In the oil obtained at Baku there is a residuum of 70 to 75 per cent. after the volatile naphtha and ordinary kerosene have been drawn off by distillation, and prior to its utilisation under boilers on this railway enormous quantities of this refuse were thrown away. Before 1882 the locomotives were fired with anthracite, but after various attempts Mr. Urquhart succeeded in altering the shape of the fire-box and tubes to burn petroleum. Up to 1894 there were about 420 miles of railway on the Grazi-Tsaritzin line, and some 150 engines were fired with

petroleum. The specific gravity of the oil used varies from 0·889 to 0·911, and its weight is 55 to 56 lbs. per cubic foot.

The tank containing the petroleum is placed for safety inside the feed-water tank in the tender. The oil is drawn from the tank through a pipe, terminating in a nozzle, and injected into the furnace. The size of the orifice has been carefully determined by experiments. A smaller tube containing steam from the boiler passes down the centre of the oil pipe; the steam and oil mingle at the mouth of the nozzle, and are injected as fine spray into the fire-box. At the junction of the tube and fire-box they are open to the atmosphere, and the air, having free access, is drawn by suction to the nozzle, and enters with the steam and oil. The force of the mingled blast is sufficient to break up the oil into very fine spray, which is driven against a firebrick division in the lower part of the fire-box, and thus still further subdivided, before it rises into the upper part of the furnace as flame. A bridge of firebrick is now used to divide the fire-box into two sections, and round and through this each jet of air, steam, and petroleum vapour has to pass. The actual arrangements of the fire-box, &c., vary of course with the class of boiler used, whether marine, horizontal, or vertical. Besides the locomotives, a great many stationary boilers are fired with petroleum. It was at first found difficult to keep the oil in a proper liquid state during the severe Russian winters. A certain quantity of solar oil (one of the lighter oils obtained from petroleum) is now added to it, and steam is carried from the locomotive boiler through the oil tank to heat it, by means of a coil of pipes.

Cost of Working.—As regards the cost of working with petroleum, the best proof of its economy is the fact that from 1882, when it was first used on this railway, to 1888, it gradually and entirely superseded coal. The saving in money is stated by Mr. Urquhart to be 43 per cent. In 1882 the consumption of coal per engine mile, including wood for lighting up, was 55·65 lbs., costing 7·64d. In 1887 30·72 lbs. of petroleum refuse were used per engine mile, costing 4·43d. The expense of repairs was also much less, owing to the absence of sulphur in the oil. Other railways in Southern Russia have now adopted petroleum as fuel. The locomotives on the Trans-Caspian lines are fired with it, as no other combustible is available, and the stores of liquid fuel have formed an important factor in the advance of Russia across Central Asia.

On the question of the evaporative power and heating value of petroleum, as compared with coal, Mr. Urquhart speaks with authority. He estimates the heating power of petroleum refuse at 19,832 B.T.U., and of an equal weight of good English coal at 14,112 B.T.U. per lb. Theoretically, 1 lb. of petroleum refuse evaporates 17·1 lbs. of water at a pressure of 8½ atmospheres, while 1 lb. of good English coal evaporates 12 lbs. of water under the same conditions. In practice he found that the

petroleum used on his engines evaporated, at this pressure, 14 lbs. water per lb., or 82 per cent. of the total possible evaporation.

Petroleum on an English Railway.—Some kinds of heavy petroleum are also utilised as fuel on the Great Eastern Railway Mr. Holden, the locomotive superintendent, finding much difficulty in getting rid of the refuse from shale oil distilleries, tar from oil gas, green oil, creasote, and other heavy residuum, has adopted a method somewhat similar to the Russian plan, for burning them under boilers instead of coal. The oil used is entirely heavy refuse, thicker and less easy to evaporate than Russian astatki. It is conveyed from the tank through a pipe, and injected into a furnace, while the air passes to the spraying nozzle through a central pipe, and steam is twice sprayed on to the petroleum before it is sufficiently volatilised to be converted into fuel. In all cases where heavy oils are broken up by injection, superheated steam is found most effectual. The injector is in three annular concentric parts. The liquid petroleum enters one passage, a jet of superheated steam passes through another, carrying with it a current of air down the central tube. Before the oil reaches the nozzle it is broken up into spray by the steam jet. After the petroleum, steam and air are sprayed into the fire-box, a separate supply of superheated steam is injected into the petroleum, and completely atomises it. The vaporised liquid strikes against brickwork in the fire-box, is broken up and forms a broad, concentrated flame. On the bars of the grate a thin layer of fuel, usually cinders mixed with chalk, is kept burning, to maintain a uniformly high temperature, decompose the oil, and ignite the spray. In the latest arrangement the air pipe is carried through the smoke-box, and heated by the waste heat from the furnace, the oil is also previously heated by the exhaust from the air brake pump. Arrangements are made to fire the boilers with oil or coal, according to the price at which either can be procured. As with the astatki burnt on the Russian railways, the oil is so thoroughly mixed with the steam and air that there is no smoke. The mixture employed by Mr. Holden consists of 2 parts coal tar and 1 part green oil. The same system of firing locomotives with oil refuse is used on the Great Western Railway in the Argentine Republic, where there are abundant oil fields. Holden's oil burning apparatus has now been adopted on several other railways, and elsewhere. It is used to burn liquid fuel under boilers as an alternative to coal, according to the market price, and the available supply of either fuel.

Petroleum for Marine Purposes.—Marine boilers have often been fired by petroleum. About 1867 experiments were made by Mr. Isherwood of the United States Navy, on board the gunboat "Pallas," on liquid petroleum as fuel. He was convinced of its superiority to coal in heating value, convenience of storage, weight, bulk, absence of stoking,

and consequent saving of manual labour. He found also that the lighter oils, which explode very easily, burn completely, and leave no deposit. Against these advantages must be set the drawback of using petroleum to any great extent as marine fuel—namely, the danger of carrying an inflammable oil, giving off volatile gases at a low temperature, in bulk at sea. There is also the difficulty of obtaining a sufficient supply of fresh water for the superheated steam. Unlike the feed water in the boiler, this water cannot be continuously used, because it escapes as steam with the furnace gases. On account of the risk, no kinds of oil but heavy residuum and astatki, which are now increasingly employed, are likely to be used at present for marine purposes, except on small ships. The oil tested by Isherwood was utilised in the same way as on the Russian and Great Eastern Railways—namely, injected into the furnace, after being thoroughly mixed with steam and air. Petroleum refuse is as cheap in America as on the shores of the Caspian.

II. **Oil Gas.**—The manufacture of gas from oil differs little in principle from the process of distilling gas from coal. The oil is dropped or poured into a retort kept at a strong heat, and the vapour given off is purified, washed, and cooled in the same way as lighting gas. All oils are not equally fit for gas making. Very heavy oils, as tar or blast-furnace oils, creasote, &c., though they are vaporised for a time by the application of heat, condense again under pressure, and cannot be converted into a fixed gas. The best way of utilising them is to burn them, as already described, under locomotive or other boilers. Oil of low specific gravity, as petroleum spirit, is too volatile and evaporates too readily. For making gas the best oils are the intermediate, such as Scotch shale oil; they are too heavy to be vaporised completely in an oil engine, but are found to yield a very rich gas, well adapted for the purpose of driving motors. Vegetable oils and animal grease, fat or dripping, can also be used in this way. Such motors, however, worked with oil gas in the same way as a gas engine is driven with lighting or cheap gas, are not oil engines, properly so-called, and must be distinguished from them. They do not, as in true oil engines, prepare the fuel for combustion, as well as utilise it in ignition and explosion. They are in reality gas engines, the gas used being distilled from oil instead of from coal. Nor is the economy so great as in oil motors, because heat must be applied, first to turn the oil into gas, and then to convert the gas into energy. In oil engines one application of heat suffices for both purposes, but the power generated is not so great.

Distillation of Oil Gas.—The method of distilling oil does not vary much in the different systems, though it is usually necessary to modify the process slightly, to suit the oil or other refuse utilised. Thus in Alsace and in parts of France where there are deposits of bituminous

schist, the crude petroleum refuse is allowed to fall in a thin stream into the retort, which is kept at a dull red heat by means of a fire beneath, and after being purified the oil gas is stored ready for use The gas obtained has twice the calorific value of the same volume of coal gas. In another process, where a wrought-iron retort is heated to a cherry red by a furnace, the gas distilled has about four times the calorific value of coal gas, and costs about 60 centimes per cubic metre. The quality of the gas depends chiefly on the temperature of the retort. In other countries various substances are successfully distilled to produce oil gas, such as linseed oil in Brazil, castor oil in Burmah, palm oil in West Africa, mutton fat in Australia and South America, and in general fatty refuse of all kinds, wherever it is found in abundance. In Great Britain oil gas is usually made from Scotch shale oil, of specific gravity 0·84 to 0·87, flashing point from 235° F. to 250° F., and yielding about 100 cubic feet of gas per gallon. The heating value of this intermediate oil is much increased, if the oil be injected into the retort by means of steam jets. The steam is decomposed by the heat; CO is formed by the combination of the oxygen in the steam and the carbon in the oil, and deposit of solid carbon is prevented. This was the method followed in Rogers' oil gas apparatus.

The first oil gas producer was introduced into England in 1815 by Mr. John Taylor, of Stratford, Essex. The oil was passed successively through two retorts, to vaporise it thoroughly. Experience has since shown that one retort, if kept steadily at a proper temperature, is sufficient to volatilise all the lighter hydrocarbons contained in the oil, and convert them into gas.

Oil Gas Producers—Mansfield.—The Mansfield oil gas apparatus is one of the oldest producers, and that most commonly used. Gas can be made in it, not only from petroleum, but from any kind of oil, fat, &c., and also from wood, coal, or coke. Fig. 126 gives an external elevation of this producer. A is the receptacle containing the oil or fat, which becomes gradually heated and liquefied, if solid, by the heat from the retort below. From here the oil passes in a thin continuous stream into the siphon pipe S, where it is vaporised, and conducted through the wide tube or hood B to the retort R, in which it is further decomposed, and made into a permanent gas. The retort is placed in the centre of a cast-iron casing O, lined with firebrick L. Before any oil is admitted the brick lining is heated, and the retort brought to a cherry-red heat, or a temperature of 1,600° to 1,800° F., by the fire under the retort. Unless combustion is carefully adjusted by means of the damper D at the top of the furnace, regulating the discharge of the products of combustion, and the openings M below, admitting the cold air, the quality of the gas is affected. The cock through which the oil passes into the pipe

S is not opened until the retort, as seen through the sight hole *p*, has been heated to a cherry red. The gases from R pass through the hood B down the stand pipe P to the hydraulic box H, where they are washed, and freed from the tarry products given off in the manufacture of gas, by forcing them through water. The hood B rests upon two sockets; *o*, above the retort, is filled with lead, which melts with the heat, the hood sinks into it, and an impervious joint is thus formed during the gas-making process. The other socket K is filled with water to prevent the escape of gas unless there is any undue pressure, when it forces its way out. At V is another safety valve, in case too much gas is produced; the tarry deposits are withdrawn through the door N. The purified gases then pass through the pipe Q to a gasholder.

Fig. 126.—Mansfield Oil Gas Producer.

Two things are necessary to make good gas in the Mansfield producer. The heat of the retort must be sufficiently intense to decompose the oil, and the stream of oil must be so regulated that no more passes in at a time than will produce a rich gas. With intermediate oil, 1,000 cubic feet of gas are made from 7 to 9½ gallons of oil, or about 100 cubic feet per gallon; the gas has a heating value of 864 B.T.U. per cubic foot. The total cost of oil and fuel, with oil at 4½d. per gallon, is about 6d. per 100 cubic feet. This is more expensive than coal gas in England, but its heating value is higher, and the gas is said to have three times the power. Abroad, where coal usually costs more than in Great Britain, power may sometimes be most cheaply obtained by an engine driven with gas made from oil or fat in a Mansfield producer. At the Melbourne Exhibition in 1888, an Otto engine was driven by gas generated from dripping or

fat, at the rate of 100 to 120 cubic feet per gallon. The flashing point of the fat was above 400° F., and it was previously liquefied by a burner. Tangye and Crossley gas engines up to 100 H.P. have been successfully driven with Mansfield oil gas in England and abroad; the consumption in a 12 H.P. Crossley motor was 10 cubic feet per B.H.P. hour. It has also been used to drive a 30 H.P. National gas engine, and there are a large number of Mansfield oil gas plants in India.

Keith.—The Keith oil gas producer is especially adapted for oil made from Scotch shale. The principle on which the gas is made is the same as in the Mansfield producer, but the process is said to be more rapid. The oil filters down through shallow iron troughs placed in the retort, till it reaches the lowest part, where the temperature is highest. Here it is converted into a gas and led off to the washer, and then direct to the gasholder, where it is cooled and stored. The pipes are large, and the pressure of the gas is kept low until it has passed to the holder. As it is principally intended to drive engines, it is unnecessary to purify it further. For illuminating purposes it is again passed through lime and sawdust, and after it has reached the holder, the pressure is raised by compression pumps to 150 lbs. per square inch. The gas produced, of 60 candle power, is exceedingly rich, and too powerful to use in a gas engine without altering the valves and passages. It is, therefore, diluted with air in an apparatus called a mixer, in the proportion of 35 parts by volume of air to 65 parts of oil gas, and is then of about the same strength as the lighting gas used in motors. It is, of course, again diluted with the proper proportion of air, when introduced into the cylinder of an engine.

The most important application of the Keith oil gas process is on the Ailsa Craig Lighthouse in Scotland. Here it supplies five 8 H.P. Otto gas engines, working the air compressors for the two fog signals. There are four air-pump cylinders, each 10 inches diameter and 18 inches stroke; they are driven at a speed of 160 revolutions, and the air is compressed to 75 lbs. per square inch. The fog signals are in different parts of the island, at a considerable distance from the air compressing station. To supply power for fog signals, which are often required at a few minutes' notice, gas engines are of special value, because they can be started without delay. In this lighthouse twelve gas retorts are used, producing 10,000 cubic feet in four hours from 100 gallons of ordinary illuminating paraffin, distilled from Scotch shale. From 20 to 30 cwts. of coal are required to heat the retorts. The four engines consume 26 cubic feet of pure oil gas per H.P. per hour, or 6·5 cubic feet for each engine. The output is rather expensive, owing to the isolated position of the lighthouse, and cost of carriage of coal and oil.

A description of the **Pintsch** oil gas system will be found at p. 313

of the Third Edition of this work. It has not hitherto been employed to drive engines, the Pintsch power gas producer (see p. 234) having been successfully utilised for that purpose.

An oil gas producer has been brought out by Messrs. Cowell and Kemp-Welch, and used to drive an engine. The plant consists of a retort enclosed in firebrick, and placed over a furnace fired with coke, but it is proposed hereafter to utilise the oil gas itself as fuel. The oil is pumped by hand into the storage tank, 9 feet abcve the floor, and thence to a smaller tank, the level in which is kept constant. Here it falls through a ball-cock with graduated scale into a funnel leading to the retort. Air is sucked by pumps through the funnel into the retort, and draws down the oil with it. The heat of the retort gasifies the oil, and it combines with the air to form a fixed gas. This is led off through a coil of cooling pipes to the washer, which is in four divisions, and the gas is passed successively through sulphate of alumina, sodium chloride, and sodium carbonate on its way to the holder. It is said to be perfectly pure, with no bye-products, when it reaches the engine. In a 6 B.H.P. engine the consumption of oil thus gasified was ·07 gallon per B.H.P. hour, and the quantity produced was 330 cubic feet of gas from 225 cubic inches of oil.

CHAPTER XVIII.

METHODS OF TREATING OIL—CARBURATORS—EARLY OIL ENGINES.

CONTENTS.—Oil Motors—Distillation of Oil—Carburators—Lothammer, Meyer—Alcohol Engines—Utilisation—Vaporisation of Oil—Early Oil Engines—Hock—Brayton—Spiel—Siemens.

Oil Motors.—Having examined the first and second methods of applying oil to produce motive power, and considered it—I. as liquid fuel, and II. as a gas—we now come to the study of oil motors, properly so-called. Gas engines, though far more handy than steam, are not suitable for every purpose for which motive force is required. For small powers, where steam cannot be used because of the complication of a boiler, nor gas, when no gas works are near, petroleum engines supply a want, and have undoubtedly a great future before them. It is a peculiarity of these motors that the fuel is delivered to them direct, so to speak, in its original condition. In a steam engine and boiler, the water must first be evaporated over a furnace; in a gas motor, the working agent must either be distilled in a retort, or produced in a generator. The fuel for a petroleum engine may be purchased almost anywhere. An oil engine is self-contained, and independent of any external adjunct; but in turning this advantage to account, the difficulties of the constructor are somewhat increased. Not only must the engine be designed to utilise the working agent, and obtain mechanical energy from it, but the working agent must itself be produced, and the fuel prepared for combustion.

There are two methods, Classes III. and IV. of the divisions in the preceding chapter, by which oil may, in the cylinder of an engine, be turned into a source of energy, viz. :—

III. Light petroleum spirit, naphtha, benzoline, or carburetted air is exploded, and drives out the piston of an engine by the expansion of the gases.

IV. Ordinary lighting or intermediate oil is also used to drive an engine by explosion and expansion, after its evaporation and conversion into petroleum spray. In Class III., atmospheric air at ordinary temperature and pressure is charged with volatile spirit; in Class IV., the petroleum is pulverised and broken up into spray by a current of air, and the application of heat. In France and Germany the lighter oils are

much used for motor purposes, while in England heavier oils are mostly employed for stationary engines, and "petrol" or petroleum spirit in motor cars and for marine work. French engines are generally worked with benzine; in Germany, where the duty on alcohol is low, it is one of the chief sources of motive power in small engines, especially when carburetted—*i.e.*, mixed with petroleum essence. It is more difficult completely to vaporise heavy petroleum, and avoid any deposit in the cylinder, than when the lighter oils are used, and engines for larger powers worked with the former are, with the exception of the Diesel and the Bánki, not in so much favour abroad as in England.

It must not be supposed, however, that all oil engines can be rigidly classed under either of these two divisions, because of the complex nature of petroleum, and the different temperatures at which it evaporates. In one engine, driving the Yarrow spirit launch, nothing was used, with due precautions, but pure petroleum spirit or ether. In a few motors, as the Priestman, the oil is so pulverised and converted into spray that the whole is evaporated, and no residuum left. Some oil engines evaporate more or less of the volatile constituents of the petroleum, with a proportionally large or small refuse, according to the amount of heat applied during the process, and the specific gravity of the oil used. The efforts of engineers, however, have of late years tended to the utilisation of ordinary petroleum, which is evaporated in the cylinder as completely as possible.

Until the last few years it was believed to be impossible effectually to vaporise oil, and render it fit for combustion in an engine cylinder, except by the use of some spray-making device. The behaviour of oil in a retort was quoted to show that it must be dealt with in some complicated way, in order to evaporate it completely. It was first pointed out by Mr. Worby Beaumont, and is now generally recognised, that the addition of air in an engine cylinder prevents the formation of oil gas and heavy residuum, and is sufficient to convert the whole of the oil into a combustible. The use of a spray-maker has therefore been discarded, except in the Priestman engine, and the process of vaporising becomes simpler in each successive oil motor produced.

There are two methods of evaporating petroleum, both used to prepare it for driving an engine—viz., hot and cold distillation. We have seen that, the less the specific gravity of the oil, the more volatile it is. The higher the temperature to which it is exposed the greater the evaporation, or the amount of hydrocarbons given off. It is only the light and highly inflammable spirit used in engines of Class III. which can be evaporated without the application of heat. The heavier oils, of greater specific gravity, must always be heated, to vaporise the larger portion of their constituents, and to counteract the cold produced by

evaporation. The greater the heat maintained in the cylinder, the higher will be the efficiency.

III. Distillation at ordinary atmospheric temperatures is produced in the following way :—Air is passed over light hydrocarbon oil (refined petroleum), and a volatile spirit is given off, impregnating the air in contact with it. This carburetted air is equal in lighting and heating properties to coal gas, and, mixed with a proper proportion of ordinary air, it is sufficiently inflammable to ignite, and to do work in the cylinder of an engine by the force of the explosion. The specific gravity of petroleum spirit varies from 0·65 to 0·70, and its flashing point is generally so low that it cannot be used for commercial purposes. Motors in which it is employed ought scarcely to be called "oil engines." The working agent is simply inflammable petroleum essence, and is perhaps best distinguished by the term usually applied to it abroad—"carburetted air." The ease with which this spirit can be obtained from ordinary petroleum by merely passing air over it shows that care is necessary. Nearly all the early petroleum motors employed it as the motive power, and this was one reason why they did not come into general use. Owing to the inflammable nature of the working agent, a prejudice existed against them, which extended to all oil motors, and was not removed, until the Priestman engine showed how ordinary oil could be utilised in the cylinder of a motor without danger. Now that the working methods of engines driven with light oils are better understood, they are again coming into favour, especially abroad. Most of the important foreign firms make two or three classes of oil engines, worked either with ordinary petroleum, benzine, or alcohol.

Engines driven with carburetted air are open to objections from an economic point of view. The continued evaporation of the more volatile portions of the petroleum leaves a heavy useless residuum, difficult to get rid of, and the cold produced by evaporation rapidly reduces the temperature of the oil, and renders it less ready to part with the lighter constituents. Explosive gases, therefore, produced by passing cold air over petroleum, are not suitable for use in an engine. These difficulties are partly remedied by placing the oil cistern or tank near the cylinder; its temperature is thus raised, and the oil is agitated, in order to bring a larger surface in contact with the air. If the oil is slightly heated, not only will evaporation proceed more quickly, but less dangerous oil, having a greater specific gravity, can be used.

Carburators.—There are many devices for producing carburetted air by passing it over petroleum spirit, but with most of them the gas obtained is only used for lighting. In America it is sometimes made in the cellar of a house, as it is wanted, for domestic purposes. In most carburators the principle is the same. Air is forced either by compres-

sion or suction through or over petroleum spirit, and becomes impregnated with the essence. In motor cars the explosive charge is generally formed simply by the suction of the piston drawing air through petroleum spirit or petrol, sprayed by the action of a second current of air. The mixture thus obtained is highly inflammable, and combustion in the cylinder is quite complete. In the *Lothammer* carburator, air at ordinary temperature is pumped into an outer reservoir, containing an inner receiver partly filled with the carburating liquid. It next passes at high pressure from the outer reservoir into tubes, which are carried down into the inner receiver below the level of the liquid. Here it is discharged through radiating horizontal pipes, and forced to pass upwards, the pressure of the air breaking up the liquid. By this process the air becomes thoroughly saturated with the volatile essence, and is then drawn off and stored. M. Lothammer claims to obtain a gas which does not lose its heating qualities, even when exposed to a temperature of $-18°$ C. on leaving the carburator. Drawings and a description of the Lothammer apparatus will be found in Chauveau.

In the *Meyer* carburator heat is employed to charge the air with petroleum essence. The oil or hydrocarbon liquid falls drop by drop into a small boiler, where it is evaporated by the heat from a burner below. The oil vapour at a high pressure next passes through an injector, where a proper proportion of air is drawn in with it, and the two are thoroughly mixed before they enter the gasholder. Production is automatic, and the bell of the gasholder is made to regulate the admission of oil to the boiler, and the size of the flame. This method is said to produce carburetted air of high heating value; it is principally used for driving engines. There are numerous other carburators, especially in France, as the Mounier, Pieplu, &c., but they chiefly furnish carburetted air for illumination. Each oil motor employs a special type of carburator, or method of vaporising the oil, and these will be described later, in the account of the various engines.

Engines driven with alcohol are now very numerous, and though properly speaking they can hardly be classed as oil engines, the working conditions are practically identical, the chief difference being in the sections of the admission valves and passages. Alcohol or spirit is obtained, as is well-known, from the fermentation of glucose, 100 lbs. of the latter yielding 51 lbs. of alcohol. The specific gravity of pure alcohol is 0·79, molecular weight 46, boiling point 78° C., chemical formula—$C_2H_5 + OH = C_2H_6O$. For commercial purposes it is usually diluted with water. Its (lower) heating value—pure—is 12,100 B.T.U. per lb. and 9,620 B.T.U. per lb. when diluted with 20 per cent. by weight, or 15 per cent. by volume of water. For use in an engine it is generally carburetted by the addition of 10 to 50 per cent. of benzol, and

the heating value of the mixture is in round numbers 12,000 B.T.U. per lb.*

Utilisation of Oil.—Professor Unwin is of opinion that the three methods of utilising petroleum, as fuel under a boiler, as oil gas, and to carburate air, are none of them capable of any wide application, owing to the expense, the difficulties of transport, and the danger of using a highly inflammable liquid. The ideal oil engine of the future is probably of the fourth class, and comprises motors using and more or less completely evaporating ordinary lighting or heavy petroleum oils. If, however, gas engines are younger and more modern than steam, and therefore have more possibilities of future development, the same applies in a still greater degree to oil motors. In some respects a greater heat efficiency, both in theory and practice, ought to be obtained from oil than from gas engines. In the latter the gas must be kept cool till it is introduced into the cylinder, and therefore, as it has hitherto been found impossible to utilise the exhaust gases to any great extent, a large proportion of the heat is wasted. In an oil engine the working agent should be at a high temperature from the first. A certain amount of heat is necessary to render the oil fit for evaporation, and this heat is sometimes supplied by making the exhaust gases circulate round the oil tank or vaporiser. The air also is sometimes previously heated by the exhaust in various ways. Hence more heat is utilised, the exhaust gases are comparatively cool at discharge, and a better working cycle should be the result. For a comparison of the heat efficiencies of oil and gas motors see Table of Tests, in which, for the highest heat efficiencies, the Diesel and Bánki oil engines head the list.

IV. In the fourth method of producing heat from oil—namely, by evaporating ordinary petroleum, and firing it as in a gas engine—the density of the oil used varies from 0·70 to 0·84. To ignite so heavy a liquid, and utilise the force of the explosion to drive a piston, the oil must be converted at a high temperature into an inflammable vapour, before it is admitted to the cylinder, and this is done in various ways. Frequently a blast of compressed air is forced into the petroleum, to break it up. All oil engines have a vaporiser or hot chamber, where the petroleum, either liquid or in the form of spray, is converted into vapour. The vaporiser is usually heated by a lamp at starting, and afterwards by the exhaust gases, or by the heat of explosion. The air for combustion is admitted and mixed with the charge of petroleum, after the latter has become vapour. The mixture is then drawn into the cylinder, as in a gas engine, by the suction of the piston. Ignition is generally by a tube, but electric ignition is often used, and a safety or non-return valve is

* For Professor Meyer's Trials of Alcohol Engines see Report in the German Agricultural Society's Papers (*Landwirthschaft Gesellschaft*), vol. lxxviii.

sometimes necessary, to prevent the flame from shooting back into the vaporiser. With these precautions ordinary lighting oil, with a flashing point of from 25° C. to 50° C., may be used to generate power, as safely as gas or steam. It has been largely adapted for marine purposes, to propel launches, small ships, barges, trawlers, &c., and on shore for portable engines; while their almost universal adoption to drive motor cars has given a phenomenal development to small oil engines.

Vaporisation of Oil.—There are three ways in which ordinary oil is treated, when employed as a combustible in an engine. In the first, as in the Priestman engine, it is broken up into spray, and thoroughly mixed with air, before it passes into the cylinder. In the second, liquid oil is injected into compressed and heated air, and instantly vaporised, as in the Hornsby-Akroyd, and the Diesel. The third method is to admit the oil in small quantities into a vaporiser maintained at a high temperature, which acts as a retort, and converts the oil into gas before it reaches the cylinder, as in the Trusty and Capitaine engines. One or other of these principles is followed in almost all oil motors, to render the petroleum fit for combustion, but a slightly different arrangement is adopted in each particular engine, for the vaporisation of the oil.

Early Oil Engines.—The earliest attempts to burn petroleum to produce mechanical energy were made soon after the introduction of gas engines. At that time, however, it was considered impossible to use ordinary petroleum, of about 0·80 specific gravity, because the difficulty of evaporating it was so great. To break it up into spray by a blast of air had not been proposed. Light petroleum spirit or inflammable ether was therefore employed, and probably retarded the development of the oil engine.

Hock (1873).—More than thirty years ago two engines appeared almost simultaneously, the Hock in Vienna, and the Brayton in America. In the Hock engine, the patent for which was taken out in 1873, benzoline or volatile hydrocarbon gas was used, drawn from a reservoir at the back of the horizontal cylinder. The engine was of the two-cycle, single-acting non-compressing type, with an explosion every revolution; the whole series of operations was carried out in one forward and return stroke. On one side of the cylinder was a small valve chest containing two valves, one for the admission of air, the other for the discharge of the exhaust gases, both worked by an eccentric from the main shaft. On the other side was the igniting apparatus. A little air pump, driven from the crank shaft, forced a current of air at each stroke into a small receiver filled with benzoline. The air became charged with benzoline, and a stream was directed through a nozzle against a permanent burner, placed close to an opening at the back of the cylinder. The

benzoline ignited at the flame, a flap covering the admission valve was lifted by the suction of the in-stroke, the flame drawn in, and the mixture in the cylinder ignited. The permanent burner was fed with petroleum spirit from the same reservoir.

The motor piston having passed the inner dead point, the suction of the out-stroke drew a small quantity of hydrocarbon, at atmospheric pressure, from the reservoir at the back through a nozzle into the cylinder. At the same time a flap valve was lifted, and a stream of air, also at atmospheric pressure, was admitted through another nozzle beside it. The two nozzles being set slightly inclined to each other, the air pulverised the benzoline, and broke it up into spray. As the charge was too rich to use, it was next diluted with a second supply of air from the valve chest. When the piston had passed through about half the stroke, ignition took place, as already described, the mixture being so arranged that the richest portion lay nearest the ignition flame. The return stroke discharged the products of combustion. The centrifugal governor driven from the crank shaft acted by regulating the supply of air from the valve chest. If the speed was increased, the valve was held open longer, a larger quantity of air was admitted, and less benzoline. When the speed was reduced, and the balls of the governor fell, less air entered, the composition of the charge became richer, and the explosions more certain and stronger. This engine was popular for a time, but it was not permanently successful, on account of the inflammable nature of the petroleum spirit used. Drawings are given by Schöttler.

Brayton (1872).—The oil engine patented by Brayton, and first constructed at Exeter, United States, was introduced into England about 1876. It was a better and more practical motor than the Hock, because the oil used was of greater density, higher flashing point, and less inflammable. Brayton was the first to employ ordinary heavy petroleum and kerosene, boiling at about 150° C., instead of light spirit or essence, in the cylinder of an engine. His engine, called the "Ready Motor," was also the first, and till then the only engine of any note, to embody the principle of combustion at constant pressure, instead of at constant volume. It was originally worked with gas, and was first brought out in America; the English patent was acquired by Messrs. Simon of Nottingham, who brought it out as a gas motor in 1878 (see p. 50). A view of the Brayton-Simon gas engine is given at Fig. 16. The charge of gas and air was ignited before its admission into the cylinder, entered in a state of flame, and drove the piston forward without any rise in pressure, a steady combustion being maintained behind it during one-third of the forward stroke. As Brayton found that the flame of the gas, in spite of the gauze diaphragm shutting it off from the pump cylinder, was apt to strike back, and ignite the compressed charge in it, he sub-

stituted ordinary petroleum, instead of gas, as the motive power. The specific gravity of the oil used was 0·850.

The chief improvement of the Brayton engine over the Hock was that both the air and the oil were admitted, at high pressure, into the motor cylinder from two separate pumps, worked by the engine. The pressure of the injection pulverised the petroleum, and the air became thoroughly impregnated. In all oil engines hitherto constructed, the use of light petroleum spirit made it unnecessary to spray the oil. The system of breaking it up by forcing a blast of air into it rendered possible the use of heavy petroleum. Brayton was therefore the inventor of the first safe and practical oil engine, and in this respect his motor was the forerunner of the Priestman.

As shown at the Paris Exhibition of 1878, the engine was vertical and single-acting, resembling the Simon at Fig. 16 (p. 50), except that the crank and distributing shaft were above the cylinder. There was an impulse every revolution. The two pistons, motor and compressor, worked downwards upon a beam joined to the motor crank by a connecting-rod. Both cylinders were of the same diameter, but the stroke of the compression pump was half that of the motor piston. From the pump, part of the compressed air was delivered direct through the carburator into the motor cylinder, and part was forced into a reservoir in the base. The air here stored was intended to equalise the pressure, and to assist in starting the engine. On the other side of the motor cylinder was a small pump worked from an eccentric on the auxiliary shaft, to inject petroleum into the carburator. The valves were actuated by cams from this auxiliary shaft, driven by bevel gear from the crank shaft. The admission cam was shifted by the governor, in order to admit more or less of the charge, according to the speed of the engine.

Fig. 127.—Brayton Carburator. 1878.

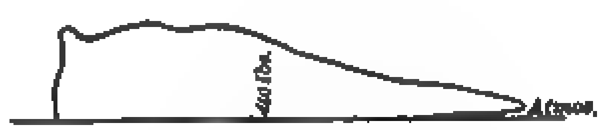

Fig. 128.—Brayton Petroleum Engine—Indicator Diagram. 1878.

Fig. 127 gives a view of the carburator in three compartments. The

carburation of the air takes place in the middle division B, which is filled with a porous substance, and separated by a layer of perforated metal plates at *p* from the space below C, communicating through an opening with the motor cylinder. The chamber C is always full of flame. Petroleum is injected from the small oil pump through pipe E, and air from the pump through F into B. The jet of air pulverises the petroleum and breaks it up into spray, which thoroughly impregnates the porous material. At the right moment the valve opens, and fresh air is drawn through O into the outer chamber A. In its onward passage through B, it carries with it a portion of the volatilised petroleum, is ignited on reaching C, and passes into the cylinder in a sheet of flame, but there is no explosion. Thus air is twice applied, first to break up the petroleum, and then to dilute it in the same way as the charge in a gas engine. When the piston has passed through one-third of its stroke, the valve S closes, and the ignited vapour expands, the two pumps meanwhile injecting a fresh charge of compressed air and petroleum into B. To start the engine, petroleum is pumped in by hand, and compressed air admitted from the reservoir, and when the carburator is full of oil vapour, the little plug at G is withdrawn, and a lighted match applied. The engine is constructed on the same principle as the Davy safety-lamp —namely, that of preventing back ignition by the use of a wire gauze, or perforated metal plates.

Trials.—A trial of a 5 H.P. American Brayton petroleum engine was made at Glasgow by Mr. Dugald Clerk in 1878. The speed was 201 revolutions per minute, and the consumption of petroleum 2·16 lbs. per I.H.P. per hour. Much of the total power developed was absorbed in driving the air and petroleum pumps. Fig. 128 gives an indicator diagram taken during the trial, in which the prolonged combustion obtained with ignition at constant pressure is seen. The construction of the Brayton engine has been given up for many years.

Spiel (1883).—Both the two motors described above were brought out before the success of the Otto engine had fully established the superiority of the compression type. In the next oil engine, patented by Spiel, and made in England by Messrs. Shirlaw & Co., Birmingham, the Beau de Rochas four-cycle is introduced, and the engine resembles the Otto in many respects. It has the drawback of using inflammable petroleum spirit of 0·700 or 0·730 specific gravity, instead of the safer heavy petroleum. Being easily volatilised, this spirit does not require so complicated a process to convert it into spray as in engines employing oil of greater density. The motor is horizontal, single-acting, and the admission, distribution, and exhaust valves are worked from an auxiliary shaft geared to the main shaft in the usual way. Ignition is by a flame carried in a slide valve, working at the back of the cylinder, the method being the

same as in the original Otto; the Spiel was probably the only oil engine firing the charge in this way.

The benzoline is drawn from the reservoir and injected into the cylinder by a small pump worked from the auxiliary shaft. When this plunger pump is driven down, it carries with it a crosshead working the air admission valve, and air enters a mixing chamber at the back of the cylinder. As the piston continues to descend, a passage is opened from the pump into the mixing chamber, a jet of petroleum spirit is sent into the air, broken into spray by striking against a projection, and the two are sucked into the cylinder by the admission stroke of the motor piston. If the speed be too great, the ball governor interposes a small projection between the valve-rod of the pump and the levers working it. The two become locked and cannot move, and the valve remains open, admitting air only to the cylinder until the speed is reduced.

Drawings of this engine are given by Robinson and Schöttler. Fig. 129 shows an indicator diagram of a Spiel oil engine, in which the consumption of oil was about 1 pint per B.H.P. per hour. In another 14 B.H.P. Spiel engine having a cylinder diameter of 9½ inches, with 18 inches stroke, and making 160 revolutions per minute, the consumption of naphtha was 0·81 lb. per B.H.P. per hour. The specific gravity of the oil used was about 0·725. It is contended that, in spite of the difficulties of storing and transporting naphtha, owing to its inflammable nature, it is greatly superior to heavy oils for producing motive power. Some interesting experiments were made with a small model engine, running at over 500 revolutions per minute, in which the Beau de Rochas cycle, comprising the operations of admission, compression, explosion plus expansion, and exhaust were carried out four times in a second. Some hundreds of these engines are said to be at work.

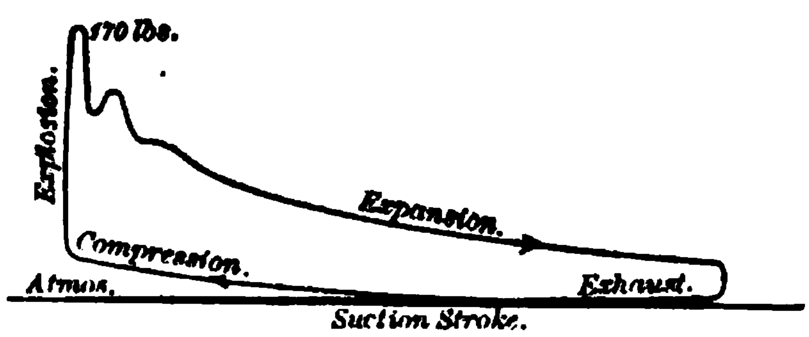

Fig. 129.—Spiel Oil Engine—Indicator Diagram.

Siemens (1861).—No account of internal combustion engines would be complete without a mention of the motors designed and patented by Sir William Siemens. In 1860 he first devoted his attention to the subject, and from that time till 1881 he brought forward various engines, all intended to illustrate the principle of utilising the waste heat of the exhaust gases, by passing them through a regenerator before discharge. The incoming mixture entered the cylinder through the same regenerator. This idea of a regenerator in heat motors originated with Dr. Robert Stirling, in 1827, but it has hitherto been found almost impossible to

apply it in practice, except in the case of air engines, though in metallurgy and other manufactures it is largely used.

Sir William Siemens made many alterations and improvements in the heat engines he designed. In one he proposed to add a gas generator, producing water gas by the passage of steam and hot air under pressure through incandescent fuel. The gas thus made was pumped into a reservoir, and from thence into four cylinders, each serving to charge the next through a regenerator formed of layers of metallic gauze. From 1846 to 1881 Sir W. Siemens took out a series of patents for internally fired engines. The last, designed not long before his death, exhibited his matured views on the subject. It embodies the principle of combustion at constant pressure, and although never worked, it is valuable as indicating possibly on what lines the heat engine of the future may be improved.

Fig. 130.—Siemens' Regenerative Engine. 1881.

The Siemens Regenerative Engine (1881) is shown in sectional elevation at Fig. 130. There are two motor cylinders A and A_1, the pistons of which work vertically through the connecting-rods C and C_1 upon the crank shaft K, at an angle of 180° apart. The cylinders are divided into two parts. The lower in each has a water cooling jacket W, the upper part is lined with fireclay. The differential pistons compress the mixture on one face during the down stroke, while the explosive gases are expanded on the other. At the top of each cylinder are the regenerators R and R_1, consisting of thin sheets of metallic gauze. All the valves for admission, distribution, and exhaust are contained in a revolving cylindrical valve F, worked from the crank shaft by equal bevel wheels G. The exhaust E is at the top, and a passage at p_1 is opened to it alternately from either cylinder. Gas and air are admitted through the pipes m and n, and ports p, to the lower part of either cylinder, during one revolution of the cylindrical valve. The suction of the up-

stroke draws them in, the down-stroke compresses them into a reservoir at the side. From here the compressed mixture passes to the upper part of the cylinders, through the regenerator and the ports p_2. The products of combustion discharged on the upper face of the piston by the up-stroke, are forced through the regenerator on their way to the atmosphere, and some of their surplus heat is stored up in it. As the fresh charge enters, drawn in by the vacuum produced by the expulsion of the exhaust gases, light hydrocarbon oil is dropped on to it from the oil tank O above, and part of the mixture is fired electrically. The remainder of the charge is immediately kindled, and flows forward as flame into the cylinder, the flame being prevented from spreading back into the reservoir by the gauze diaphragm of the regenerator. The piston is driven down by the expansion of the gases, and compresses below it a fresh charge into the reservoir; during the up-stroke the cylindrical valve opens communication with the exhaust.

Two ingenious and economical ideas are embodied in this engine. Some of the heat of combustion is stored in the regenerator, and imparted to the fresh charge, and inflammable oil is used to mix with the gas, and render it easier to ignite. Neither of these innovations has hitherto been applied to any extent, in practice, to gas or oil engines.

CHAPTER XIX.

WORKING METHOD IN OIL ENGINES—THE PRIESTMAN OIL ENGINE AND YARROW SPIRIT LAUNCH.

CONTENTS.—Requisites in Oil Engines—Classification—Oil Engine Cycle—Construction—Valves—Ignition—Vaporiser—Lamp—Governor—Priestman Oil Engine—Spray Maker—Vaporiser—Governor—Trials—American Type—Zephyr Spirit Launch.

IF Otto can claim the honour of having made the gas engine a practical working success, after the efforts of Lenoir, Hugon, and others, the same credit belongs to Messrs. Priestman as regards oil engines. Long before the introduction of their motor into this country, oil engines had been designed and worked, but there was a prejudice against them, because of the inflammable petroleum spirit with which they were chiefly driven. The Brayton, the only engine using non-explosive petroleum, had never become popular, owing probably to the imperfections in its cycle, its extravagant consumption of oil, and low mechanical efficiency. Whatever the cause, oil engines were scarcely known or used until the appearance of the Priestman in 1888. About this time Messrs. Priestman acquired Etève's patent, and their oil motor was introduced at the Nottingham Agricultural Show in the same year.

Requisites of Oil Engines.—In any engine intended to supply the deficiencies, and remedy the drawbacks of gas or steam, the following points must be considered:—It should be—I. Self-contained, having everything requisite for its efficient working for a certain length of time. II. Safe and simple, using as the working agent a combustible which is neither difficult to procure, nor dangerous to transport. III. Easy to handle, so that any ordinary unskilled workman can drive it. This is advisable, because these engines are frequently placed in the hands of labourers without any knowledge of machinery. IV. Compact, and easily transported from place to place. V. Economical in working.

Many petroleum engines were originally constructed to use gas as the motive power, and the oil vaporising apparatus was added afterwards. Almost all oil motors employ the usual gas engine cycle, the series of operations proposed by Beau de Rochas and adopted by Otto, comprised in four strokes of the piston, with one explosion every two revolutions. Excellent results are obtained with this cycle, and as a

rule the engines run at a higher speed than gas motors. The action and method of utilising the power is the same as has already been described, the difference consists in the treatment of the petroleum. In no two motors is the process precisely the same, though in all the oil is broken up by the addition of air, and vaporised by applying heat. The following classification, given in *The Engineer*, June 24, 1892, of the methods by which the oil is evaporated, may be found useful:—

Classification.

Spray-maker.	1. Engines in which the oil, before entering the cylinder, is converted first into oil spray, forming an oil shower, and next into vapour in a hot chamber.
No Spray-maker.	2. Engines in which the liquid oil is injected into a prolongation of the engine cylinder, a hot cartridge chamber or combustion space, where it is converted into vapour or gas. 3. Engines in which the oil is converted into vapour or gas in a chamber contiguous to the cylinder, and communicating with it by a valve. 4. Engines in which the oil is converted into vapour or gas in a separate chamber, heated apart from the cylinder.

The charge thus prepared for use is fired in one of the three following ways:—

1. By electricity.
2. By a tube heated by an oil lamp.
3. By spontaneous ignition of the oil vapour, due to compression and the heat of the vaporising chamber.

Oil Engine Cycle.—Much has been done within the last few years to increase our knowledge of the cycle of heat in oil, as distinguished from gas engines. The subject has been most carefully studied and investigated by German scientific men and engineers, foremost among whom is Professor Meyer, to whose admirable researches the author was greatly indebted. It is now known that, in a few important respects, heat, when applied to oil, produces a different effect to that obtained in gas engine cylinders, and necessitates several changes in the standard type of construction of internal combustion motors. The valve gear, ignition, method of governing, and especially the vaporisation of the oil, all require and have lately received special attention. It is most important to obtain the maximum explosive pressure, and this is best produced by thoroughly mixing the air and oil vapour previous to combustion. Professor Robinson has also made valuable contributions to our knowledge of the nature and properties of oil. These researches have been already mentioned, and should be carefully noted by students.

In his opinion one of the essential points in the oil engine cycle is accurately to measure and control the quantity of oil admitted to the cylinder per stroke, and this has been more scientifically done in modern engines of late years than formerly.

The classification adopted by Professor Meyer, and by most German authorities, is perhaps more practical than that given above, and better corresponds to our present knowledge of what takes place in an oil engine cylinder. In their methods of dealing with the charge, he divides oil engines into two classes. In the one, as in gas engines, the finely-divided oil and air are mixed outside the admission valve, the oil being either conveyed to it by a pump, or flowing by gravity from a receiver above. In the second class there are two admission valves in different parts of the compression space. The oil enters through one, with sufficient air to spray it, while the main volume of air is admitted through the other, and the explosive charge is formed in the cylinder, at the end of the compression stroke.

Oil motors may, therefore, be thus classified:—

Class I.—Engines in which the oil and air are mixed before admission to the cylinder, and then vaporised. These engines have an oil valve or pump, admission and exhaust valves.

Class II.—Engines in which the oil and air are mixed in the cylinder itself, after vaporisation. These engines have an exhaust valve, spraying valve with or without a pump, and air valve.

We will now consider the chief parts of an oil motor, in which it differs from a gas engine.

Valves.—Three valves are required for the admission of the working fluid to the cylinder and its discharge—the exhaust valve, which seldom varies in type; the oil valve, and the admission, properly so called, or vapour valve, to admit the charge after mixing. Lift valves are almost invariably used. The exhaust valve is nearly always positively driven by a lever and cam, or their equivalent. The other two valves may be automatic, their "lift" depending on the lower pressure in the cylinder during the suction stroke, and their fall on the re-established equilibrium of pressure. If the admission valve does not rise, the vacuum in the cylinder increases, and eventually causes it to lift. The action of the smaller oil valve is not equally certain, and therefore it is often mechanically driven, unless permanently connected to the admission valve. Thus the oil and air valves are sometimes automatic, but the oil pump is always driven, and many makers prefer, especially with large engines, to work all the valves mechanically.

Ignition is often by hot tube, but electric ignition is much used for larger engines, chiefly on the Continent, and spontaneous ignition, as in the Diesel engine (Chap. xxiii.), is now frequent. Engines which adopt

the latter method of firing the charge, and dispense with an external flame, usually belong to Class II. In all but the smallest sizes, when working without a lamp, flame, or electric spark, some part of the cylinder near the cover must be kept at a red heat, to ignite the charge. This portion should not project sideways into the cylinder, like an ordinary ignition tube, because, however carefully covered, loss of heat by radiation cannot be prevented, and the heat generated by explosion would not be sufficient to counteract it. If this hot zone be located in the cylinder itself, and the explosive mixture carried past it, when already mixed with air, and therefore inflammable, it would almost certainly ignite prematurely during the admission stroke. In engines of Class II., a zone sufficiently hot to fire the charge can be arranged in the cylinder itself, and, as only oil passes it during the admission stroke, premature ignition cannot take place. The air is introduced separately, and only reaches the hot zone at the end of the compression stroke, and as this air is already heated by compression, it does not cool the hot part as it would do, if brought in contact with it immediately after admission.

The keynote of the latest efforts to ameliorate the cycle in internal combustion engines is higher compression of the charge previous to ignition. Scientific men and engineers are now universally of opinion that in greater compression lies the secret of economy. In gas engines, the limit of compression depends practically on the tightness of the valves and piston rings; but in oil motors, if the charge of oil vapour and air be too highly compressed, premature spontaneous ignition occurs, which should always be avoided. Hence the necessity, as already shown, of compressing the oil and air separately. This is done to a certain extent in the Capitaine motor, where only a very small quantity of air, sufficient to vaporise, but not to ignite the charge, is first admitted to mix with the oil, and in the Diesel, where the whole of the air is separately and highly compressed, and a minute quantity of oil injected into it at the end of the compression stroke. The same result is aimed at, more or less, in most of the latest oil engines, and, in a few, water injections serve the same purpose.

Vaporiser.—This is one of the most important parts of an oil motor, and upon its shape, temperature, and position the successful working of the engine depends. To ignite a mixture of oil and air in a cylinder properly, the oil should be well pulverised, to divide it into very fine particles. These evaporate when brought in contact with the hot tube, ignite, and communicate their heat to other particles, causing propagation of the flame, especially if the oil and air are mixed in right proportions, and highly compressed. Mere pulverisation of the charge is not, however, sufficient, it must be vaporised as well. All the oil is never

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pulverised, drops remain in the mixture which, if there is any change of direction in the pipes leading to the cylinder, are projected and thrown against the walls. Vaporisation breaks up these drops, if the walls of the compression space and oil pipe are kept at a suitable temperature. During the admission stroke the piston uncovers portions of the cylinder, the temperature of which cannot be much higher than that of the water in the circulating jacket, and against these cooler surfaces the oil will condense in a similar way to steam in a steam cylinder. These large surfaces should as much as possible be reduced to a minimum, and the oil kept hot enough to diminish this condensation.

In engines of Class I., if the compression pressure be diminished to avoid the danger of violent explosions, the heat efficiency will be reduced. As long as the vaporiser is not allowed to get too hot, and its temperature adjusted to the degree of compression, the engine will work well and quietly, but it is difficult to regulate the heat of this part of the engine. The vaporiser should not be too large, or too much of the charge will remain in it. It is heated either directly by a flame, or indirectly by the heat from the explosions in the cylinder, and the exhaust gases. If protected from radiation, it may even become hotter in the latter than in the former case.

In engines of Class II., where most of the air does not come in contact with the vaporiser, the latter can be at a much higher temperature, without the danger of premature ignition. It may indeed be so hot that it serves for ignition, when there is no timing valve. It is necessary, however, to guard against having so high a temperature in the vaporiser that oil gas is formed, with tarry and solid carbon deposits. This is usually prevented by the addition of some of the products from the former charge, and the excess of air admitted, which together hold the heavier hydrocarbons in the petroleum vapour in suspension. The oil should be broken up, and completely burnt, before there is time for the heavier hydrocarbons to decompose. Experiments, however, are still needed to determine whether combustion in engines of Class II. is as complete as in Class I. The consumption of oil is about the same.

In the best motors the average consumption may be taken at ¾ lb. oil per B.H.P. hour, but it is often 1 to 1¼ lbs. (see Table of Tests No. 9). Condensation and incomplete combustion, especially when running with light loads, must be taken into account. If the consumption exceeds about 1 lb. oil per B.H.P. hour, the volume of air in the cylinder may not be sufficient to ensure complete combustion. Sharp curves and "elbows" in the parts should be avoided. To improve the construction of oil engines, which is much to be desired, the admission, breaking up, and vaporisation of the oil—in fact, its "handling" from the moment it enters the engine—should be carefully studied. According to a German

authority, Herr Dopp, it should be completely converted into vapour by external application of heat, and upon its more or less complete vaporisation and combustion the consumption depends. The necessity of great heat in vaporising heavy oil was not at first understood, probably because in the early oil motors only light petroleum was used. Unless this heat be applied the charge is not homogeneous, and its composition fluctuates in a way the engineer cannot control, while if combustion be incomplete the engine becomes foul, and the valves and governor do not work properly. To test the combustion, a sheet of white paper may be held over the end of the exhaust pipe, when the engine is well under load. If the oil is perfectly vaporised and burnt, no oil drops should be found on the paper.

Lamp.—In most oil engines special petroleum lamps are required to heat the ignition tube, and most of them are on the same principle. The oil pipe is led round the flame to evaporate the oil, which issues out in a fine spray, together with sufficient air for its combustion. The oil either flows to the lamp by gravity, or is forced by an air pump worked by hand into a vessel at high pressure; the latter arrangement seems to be the best, and is used in many engines. The reservoir containing the oil is fitted with a pressure gauge, and is sufficiently strong for a pressure of 20 to 25 lbs. per square inch. It has a funnel with air-tight joint, and an air pump with piston and delivery valve. The end of the supply pipe to the burner is about 1 inch from the bottom of the reservoir. The burner or lamp, which has no wick, consists—in the Roots and other oil engines—of a bent tube filled with oil in a cylindrical casing, a clear passage being left through the centre of the casing for the flame. The length of the coil presents a sufficient heating surface to the flame to vaporise the oil. The latter, sent on from the reservoir by the air pressure, is thus completely vaporised before it escapes from the bottom of the coil, and is ignited. Thus the lamp provides the heat for its own vaporisation.

To start the engine, the burner is first heated by a piece of asbestos or cotton waste dipped in oil, and the air pump worked by hand till the requisite pressure is attained. The pressure of air forces the oil through the pipe to the burner, a current of air is carried with it, and thus the oil, when it issues out at the bottom of the coil, is not only vaporised but mixed with air, and burns with a strong flame, and considerable noise.

Another kind of lamp, often used in small engines to heat the vaporiser, is of what is called the blast type, and consists of a circular lamp with a little vertical air pump inside it. The rod of the pump is worked by hand, and gives a pressure of air on the top of the oil, forcing it out to the wick. A few strokes of the air pump furnish a pressure sufficient to last for some time. When in proper working order the lamp makes a loud noise, and this is an indication of the pressure of air.

Governor.—To regulate the speed of an oil engine by cutting off the supply of oil, and passing air only through the cylinder, is not altogether desirable. If the exhaust gases be utilised to heat the vaporiser, no heat can be communicated to it if there are no explosions. The vaporiser becomes chilled, and the next time oil is admitted, the temperature not

being high enough to evaporate it completely, unburnt oil passes through the cylinder. As oil engines are made chiefly in the smaller sizes, however, the speed is generally controlled, in English motors, on the "hit-and-miss" principle. If engines of Class II. are governed by holding the exhaust open, the products when drawn back into the cylinder cool it so much that, at the next explosion, the charge will not ignite. The valve should be held closed, and the heat retained.

We will now consider the different types of oil engines.

Priestman.—This engine uses almost any kind of heavy oil. It works best with common petroleum, having a specific gravity of about 0·80, and flashing point 100° F., but it may also be driven with heavy Scotch paraffin, of 0·820 specific gravity, and flashing point 150° F. and upwards. Of course, the heavier the oil the thicker will be the residuum, and the more carbon will be deposited inside the engine. These very

Fig. 132.—Priestman Oil Engine.

heavy oils cannot be properly treated in an engine cylinder, by raising the temperature, because if the oil is too much heated, it is converted into oil gas, and tarry deposits are formed. Very high temperatures are also undesirable because they reduce the weight of oil admitted per stroke, and thus the power developed. The proper temperature of the charge of oil vapour and air, on entering the cylinder, has been determined by experiments at from 170° to 300° F., according to the size of engine. The proportions are 191 cubic feet of air to ·015 cubic inch of oil vapour, for a 1 H.P. engine.

Fig. 131 gives an elevation, and Fig. 132 a sectional view of the cylinder, water jacket, and valves of the Priestman oil engine. Both drawings, as well as several of the following details, are taken from Professor Unwin's paper in the *Proceedings of the Institution of Civil Engineers*, vol. cix., 1892. The horizontal motor cylinder A is divided from the compression space C, the proportional volume of the two being

—clearance or compression, 88 cubic inches; volume described by the piston, 191 cubic inches, for a 1 H.P. nominal engine. The piston P works on to the crank shaft through a connecting-rod. At the back of the cylinder are two lift valves, inlet and exhaust, the latter is worked by an eccentric *k* on the auxiliary shaft, revolving at half the speed of the crank shaft.

Spray Maker.—The chief parts of the engine are the vaporiser and spray maker, shown below the cylinder (Fig. 131). The oil tank in Fig. 131 is under the crank shaft, and when full, is sufficient to last for two or three days. A glass gauge shows the level of oil. A small air pump J is worked by the eccentric *k*, which also drives the exhaust valve. The air is filtered through gauze, and compressed into the oil tank at a pressure of 8 to 25 lbs. per square inch above atmosphere. This pressure forces two streams of oil and air into the spray maker S, from whence they are injected into the vaporiser. At starting, the oil and air are sent

↓ oil

Fig. 133.—Priestman Oil Engine—Spray Maker.

Fig. 134.—Priestman Oil Engine—Vaporiser.

through the same cock to a small lamp below the vaporiser, which serves to heat it up.

The spray maker, seen at Fig. 133, is one of the most ingenious parts of the motor. According to the makers, the pulverisation of the oil and its complete mixture with the air depend on the shape of the two nozzles, as shown, and their exact form was only determined after numerous experiments. The oil passes through the central tube in a small stream, and the air surrounding it is turned back with considerable force to meet it, the result being that the oil is driven out in a spray as fine as is required. Fig. 134 shows the vaporiser, the method of regulating the supply by the governor, and of admitting the air necessary for the charge. As the oil and air enter, the in-stroke of the motor piston lifts the non-return valve G, and draws into the vaporiser a supply of air from outside through the throttle valve F. This auxiliary charge passes

through a number of fine holes *d d* in the circular air passage of the vaporiser *b b*. The sudden inrush of fresh air sweeps forward the oil and air with it into the cylinder.

Vaporiser.—The vaporiser is divided into two parts. In the first the oil and compressed air are mixed with, and broken up by, the air admitted through F; in the second the charge is vaporised by the heat from the exhaust gases which, at a temperature of about 600° F., are led through pipe H (Fig. 131) round the vaporising chamber, before being allowed to escape into the atmosphere. As in many other oil engines, air is twice admitted, a small quantity to spray the oil, and the bulk afterwards, to mix with it, and form the explosive charge. The vaporiser is contained in the frame of the engine, under the cylinder, as seen at Fig. 131.

Governor.—The speed of the engine is regulated by means of the spindle S above the throttle valve (Fig. 134). It contains a small V-shaped opening at *f* through which the oil is admitted from the tank to the spray maker, and the wing of the valve F is keyed to the lower part of the same spindle. The section of the orifice can be regulated to admit a given quantity of oil. If the speed is too great, the centrifugal governor drives down the spindle, contracts the opening, and at the same time acts upon the throttle valve, and reduces the quantity of air passing to the vaporiser. Thus the strength of the explosions is varied, the proportions of oil and air being always the same per stroke, and no explosions are missed. The charge then passes through the automatic admission valve *n* (Fig. 132), to the back of the cylinder, where the usual series of operations in four-cycle motors takes place. Electric ignition is used, the spark to fire the charge being generated by means of two platinum wires in a battery, shown to the left in Fig. 131; contact is established by a projection on the eccentric-rod. Tube ignition is also sometimes employed.

The shaft driving eccentric *k* causes the electric ignition of the charge, works the valve *e* to open the exhaust, and drives the small air pump J. A small hand pump *h* (Fig. 131) is used to force air at a pressure of 20 lbs. per square inch into the oil tank, before the engine is at work. To start it, a supply of oil from the tank is sent by the pump to the lamp below the vaporiser. After lighting the lamp, a few turns by hand are given to the flywheel to draw a charge into the cylinder, the electric current is switched on, and the engine begins to work. The oil tank and vaporiser are easily accessible through the opening in the frame.

In the latest types a minute quantity of water is injected into the cylinder, when the engine is working at full load. A valve opening into the water jacket, and held on its seat by a spring, communicates through a pipe attached to the hole for the indicator cock with a graduated cock,

and the supply of water is thus regulated. The suction of the motor piston at maximum load opens the valve, the water is drawn in, and mixes with the charge. On the advantage of water injections see p. 337.

Although the pressure with petroleum vapour rises more rapidly than with gas, the curve of pressures, shown by the indicator diagram of the Priestman engine, does not rise as high as in gas motors, owing partly to the larger compression space. The engine requires no lubrication. A small portion of the oil is condensed during the compression stroke, deposited upon the inner surfaces of the cylinder, and forms a layer of grease. As the fuel used is heavy mineral oil, it is not inflammable. Some interesting experiments to prove this have been made by Professor Robinson, who exhibited an engine before the Society of Arts in May,

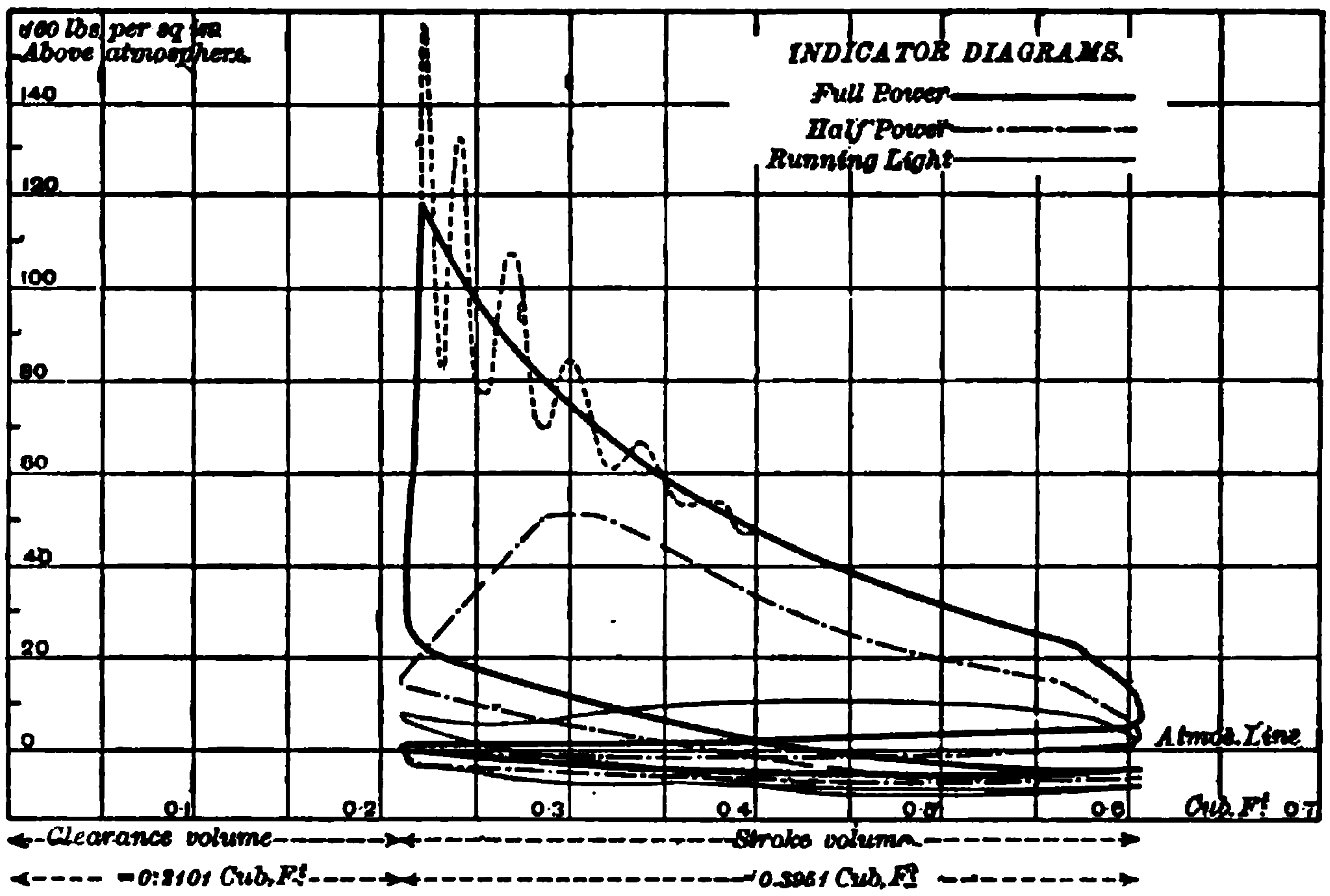

Fig. 135.—Priestman Oil Engine—Indicator Diagram.

1891, in which the air was shut off from the vaporiser, and oil alone injected. A lighted match held to this oil jet would not ignite, but it was readily fired as soon as the air was again admitted to divide and break it up.

The first portable Priestman oil engine of 6 H.P. was exhibited at the Jubilee Meeting of the Agricultural Society in 1889. In this engine the water from a tank was circulated in the cylinder jacket by a pump driven from an eccentric. The construction and working were similar to those of the horizontal single-cylinder motor.

Trials.—Several excellent trials have already been made on this engine, chiefly by Professor Unwin. In 1889 he tested, at the Agricultural Show at Plymouth, a 5 H.P. horizontal Priestman motor, with $8\frac{1}{2}$-inch cylinder and 12-inch stroke. Five trials were made with two kinds of oil, and every care was taken to ensure accurate results. In the

first test an American oil was used, of 0·793 density, flashing point 77° F., and heating value about 19,700 B.T.U. per lb. The four other trials were made with Russian oil, of density 0·822, flashing point 86° F., and a calorimetric value of 19,500 B.T.U. per lb. Fig. 135 gives a diagram taken during the trials with Russian oil. In trials at full power the following results were obtained:—

RESULTS OF TRIAL BY PROFESSOR UNWIN ON A 5 H.P. PRIESTMAN ENGINE.

Name of Oil.	No. of Revolutions per Minute.	Mean Effective Pressure Lbs. per Sq. Inch.	B.H.P.	I.H.P.	Mechanical Efficiency.	Oil Used per B.H.P. hour.	Oil Used per I.H.P. hour.
						Lb.	Lb.
American "Daylight,".	204	53·20	7·72	9·36	0·82	0·84	0·69
Russian, . . .	207	41·38	6·76	7·40	0·91	0·94	0·86

The heat expenditure was as follows:—Heat utilised, 16·12 per cent.; carried away in jacket water, 47·54 per cent.; in exhaust gases, 26·72 per cent.; lost by radiation and unaccounted for, 9·61 per cent. The engine was examined at the end of the trials, and found to be perfectly clean and free from soot or deposit, and the points of the electric wires were not coated with carbon. Another trial was carried out on a Priestman engine developing 6·76 B.H.P., by Professor Unwin at Hull in 1891. With Russian oil the consumption was 0·94 lb. per B.H.P., and 0·86 lb. per I.H.P. per hour. Details of these and other trials will be found in Professor Unwin's paper already quoted.

Another trial was made in 1890 by Mr. W. T. Douglass on a 25·5 B.H.P. double-cylinder Priestman engine, driving an electric plant, in which the consumption was 1·1 lbs. of oil per B.H.P. per hour. The progressive decrease in the oil consumption per H.P. in these engines is striking. In 1888 1·73 lbs. of oil was required per B.H.P. per hour, in 1889 1·42 lbs. At Plymouth the consumption was 1·24 lbs., and in the trials by Professor Unwin in 1891, 0·94 lb. per B.H.P. per hour. A trial was also made at Nottingham in December, 1900, by Professor Robinson on a 10·75 B.H.P. engine. The oil used was American Royal Daylight, of 0·79 specific gravity, and 18,800 B.T.U. per lb. heating value. The consumption was 1·05 lbs. per B.H.P. hour. For further details see Table No. 9.

American Type.—The engine has been taken up by a firm in the United States, where oil is cheap. It is in considerable request, because it utilises heavy cheap petroleum distillate, and the arrangements for atomising the oil have lately been improved. A new method of igniting the charge has been introduced, which is said in some respects to be

better than electricity. The low cost of petroleum refuse in America makes this engine, in which it can be burnt without difficulty, popular in the United States.

Messrs. Priestman make their engines horizontal and vertical, in sizes from 1 B.H.P. upwards. The larger sizes have two cylinders side by side. The horizontal engines run at from 300 revolutions for smaller sizes, up to 160 revolutions for the largest, vertical engines from 350 to 190 revolutions per minute. A patent self-starter for the larger sizes has been introduced, by means of which a charge of air is compressed by hand into the motor cylinder, carrying with it a sufficient quantity of oil vapour to explode by contact with the electric spark. For marine work the Priestman is also used as a vertical two-cylinder, single-acting engine, the working method being the same as already described. For large power marine motors it is made vertical, double-acting, with cylinder closed at both ends, and an explosion alternately on either face of the motor piston. The valves are worked by cams from a vertical auxiliary shaft. These engines are fitted with a reversible M'Glasson blade propeller.

Zephyr Spirit Launch.—The Yarrow "Zephyr" spirit launch is worked with pure, volatile petroleum spirit, having a density of 0·68, and evaporated in the same way as steam. Its evaporative power, and therefore its heating value, is about 12 per cent. less than ordinary kerosene, but it has a higher pressure for a given temperature than steam, as shown by Professor Robinson's tests. At a temperature of 155° F. it has a pressure of 10 lbs. per square inch. At 212° F. (the temperature of boiling water) its pressure is 40 lbs. per square inch, while at 300° F., with steam equal to 50 lbs. pressure per square inch, petroleum spirit has a pressure of about 115 lbs. It is easily evaporated, and may be cooled without condensing to a temperature of 130° F. Thus the range of temperature is greater, for the same pressures, with petroleum spirit than with steam, and since efficiency depends theoretically upon this range, more work should be obtained under similar conditions.

As petroleum spirit evaporates at a lower temperature than steam, less heat is put into it to raise it to the same pressure; in other words, if the same amount of heat be applied to it as to steam, a much higher pressure and more work are produced. But as less heat is required to evaporate it, less heat is withdrawn in the exhaust; the quantities of heat both imparted and abstracted are smaller than with steam, for a given amount of work. At atmospheric pressure nine times as much spirit as water will be evaporated by the same amount of heat, but the spirit being very volatile, it does not increase as much in volume, and only expands to one-fifth the volume of steam.

In the "Zephyr" launch, the spirit is introduced into a spiral coil

enclosed within a casing of non-conducting material, to which heat is applied; the spirit is evaporated, and, passing into the cylinder, drives the piston forward by its pressure. The exhaust products are discharged into cooling pipes, where they are liquefied and forced back to the supply tank, the inflammable spirit not being brought into contact with the air. Thus the same spirit is used over and over again, with very little waste, and the working principle and action are similar to those of a surface condensing steam engine. Ordinary heavy petroleum is generally employed to heat the spirit. A small air pump driven by the engine forces air into the oil tank, and a mixture of oil vapour and air is injected as spray into the fire-box or furnace beneath the coil, in the same way as liquid fuel under a locomotive boiler. After being completely vaporised by the heat it is mixed with more air, and burns with a continuous flame like a Bunsen burner.

CHAPTER XX.

OTHER BRITISH OIL ENGINES.

CONTENTS.—Hornsby-Akroyd—Latest Type—Trials—Trusty—Roots-Vosper—Crossley-Otto—Griffin—Rocket—Fielding & Platt—Robey-Saurer—Premier—Tangye—Howard—Clarke-Chapman—Clayton & Shuttleworth—Campbell—Kynoch-Forward—Britannia—Blackstone—Globe—Cundall—Ideal—Gardner—Nayler—Brown & May—Newton—Ruston—Capel—Dudbridge—Drake—Acmé—Petter.

THE **Hornsby-Akroyd** oil engine (1892) was one of the first in which the method was introduced of firing the charge, known as "spontaneous ignition," without either a hot tube or electric spark. The oil is injected by a small pump, worked by a cam on the side shaft, into the hot vaporiser at the back of the cylinder, into which heated air, compressed by the back stroke of the piston, is forced as it reaches the inner dead point, and the mixture ignites spontaneously. The internal surface of the vaporiser is provided with radiating ribs, to afford a greater heating area. It is maintained at a red heat by the combustion and explosion of the oil and air at every other stroke. This system has been introduced into many other engines, English and foreign. The motor is of the usual four-cycle type; the method of vaporising the oil will be best understood from Fig. 136.

Here B is the compression space, into which the piston does not enter, and C the combustion chamber beyond it. The walls of the cylinder and the valve chest are cooled by a water jacket. The highly heated charge is prevented, by the intermediate compression space B, from coming in contact with the cooler cylinder walls. Below is the lamp L of cast iron, with an asbestos wick, used to heat the combustion chamber or vaporiser at starting. Air is admitted above it from a fan F worked by hand, and as it enters it rapidly brings the oil to a strong flame, which issues through the hole at the top, and in a few minutes heats the vaporiser C. As soon as the latter is red hot, the current of air is stopped, the lamp extinguished, and the engine works automatically, after a few turns of the flywheel by hand. The T-shaped air and exhaust valves, seen at *c* and *d*, are worked by cams and levers through an auxiliary shaft, geared to the crank shaft 2 to 1, and communicate with the cylinder through the same opening, in order that the heat of the exhaust products may warm the fresh air admitted through valve *d*. Between the vaporiser and the admission chamber

is a water-jacketed back pressure valve, to prevent the possibility of premature ignition.

As the piston reaches the inner dead point, it forces the compressed

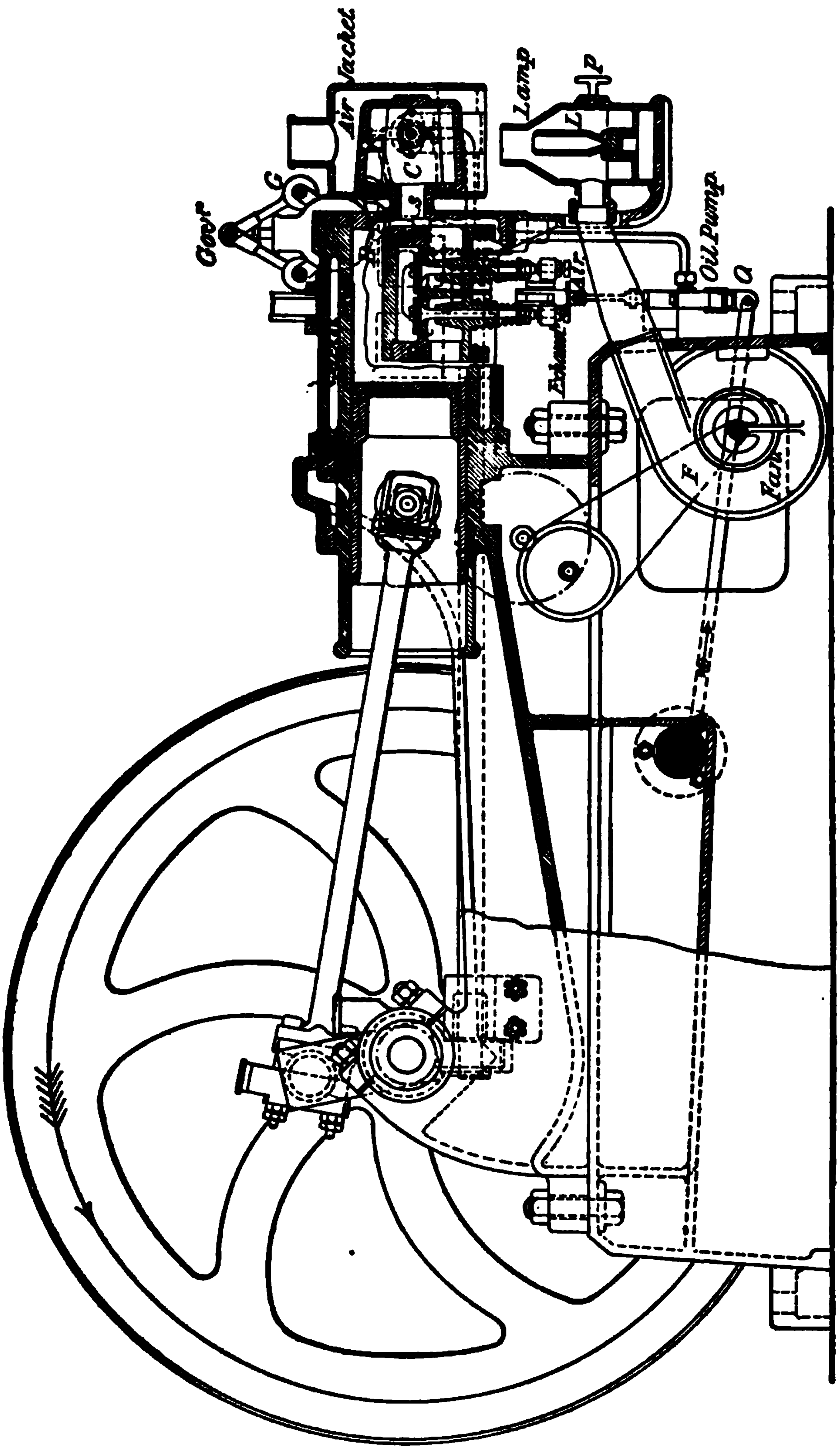

Fig. 136.—Hornsby-Akroyd Engine—Sectional Elevation.

air into the hot vaporiser C, where a small quantity of oil is injected into it through a nozzle by the little oil pump O, the amount being

regulated by adjusting the stroke of the oil plunger. This pump delivers the oil in a liquid condition, and not, as in some other oil engines, in the form of spray. The heat of chamber C and the pressure of the air charge immediately vaporise it; the maximum pressure at the inner dead point produces ignition, and the piston is driven out. The burning charge passes into the compression space of the cylinder through a contracted passage *s*. The centrifugal governor G acts on the valve through which the oil is admitted to the vaporiser, and closes the narrow tube when the speed exceeds the normal limits. At the same time it opens a little bye-pass valve, and the oil is sent back to the tank; thus the oil pump works continuously, the governor regulating only the direction in which the oil passes. The larger engines, from 20 B.H.P. and upwards, are started by means of air compressed to a pressure of 60 lbs. per square inch in a separate reservoir. The motor is lubricated in the usual way.

Method of Vaporising the Oil.—The peculiar feature of this engine is, that no attempt is made to vaporise the oil or convert it into spray, until it is actually injected into the combustion chamber. Hence the density of the oil is a point of no importance, and heavier petroleum may be used than in most other engines. The specific gravity of the oil varies from 0·79 to 0·88, and even crude oil may sometimes be utilised. The quantity of oil injected at a time is very small, only about ·033 cubic inch per stroke of the oil pump in a 6 H.P. engine. The proportion of air admitted is sufficient for complete combustion, and there is said to be no heavy residuum. The exhaust products are used to warm the incoming air, the heat of combustion to vaporise the oil, and raise the temperature of the next charge to the ignition point. Much of the heat generated is thus utilised. The consumption of the engine is said to be about ·75 pint oil per B.H.P. hour. Fig. 137 gives an indicator diagram of a 6·74 H.P. engine.

Fig. 137.—Hornsby-Akroyd Engine—Indicator Diagram.

Several interesting novelties have been introduced in the latest types. Chief among these is the arrangement for varying the size of the compression space and vaporiser, by means of a hollow covering plate at the side, and a block or projection. Both can either be turned in and project into the compression space, or the covering plate alone projects, the block fitting into a recess, or both may be turned outwards to form a projection outside the vaporiser. Thus three different sizes of the compression space and three different degrees of compression can

be obtained, according to the kind of oil used. The part of the vaporiser next the cylinder is surrounded by a water jacket, the outer part, where the oil is vaporised, is only cooled by air. The oil inlet valve is protected from the heat of the vaporiser by a collar round the neck of the narrow opening, which checks the flow of heat from the vaporiser to the valve. In the latest engines the vaporiser is heated at starting by a coil lamp, consisting of a cup containing a wick and petroleum, and a coil of pipes above it, into which the oil is forced by the pressure of air produced in the reservoir by a small hand pump. The valve box and part of the vaporiser are separately cooled with water, to regulate the temperature in the cylinder. In the 100 B.H.P. engine the piston is cooled with water supplied by a pump through telescoping tubes, as in the Koerting.

A trial of a 25 B.H.P. engine was made by Professor Robinson in 1898, in which Russian oil was used of 0·82 specific gravity, and 19,100 B.T.U. per lb. heating value. Heat efficiency per B.H.P. 18 per cent. Flashing point 90° F. Consumption of oil 0·74 lb. per B.H.P. hour. Full details will be found in Table No. 9. An earlier trial was made in 1893 on a 5 B.H.P. engine. Messrs. Hornsby construct engines single cylinder, single-acting, horizontal, stationary, from 1½ to 50 B.H.P., and also in sizes of 80, 100, 125, 160, and up to 500 H.P.; a motor of the latter size is now in course of construction. Portable engines vary from 1½ to 25 H.P. They run at 270 to 170 revolutions per minute, with a piston speed of 450 to 700 feet. The Hornsby is specially adapted for agricultural or other rough work, because no external flame is required, and as a portable motor it is much used. In this type the pressure of the exhaust gases is utilised to create a current of air for cooling the water. Many hundreds are now at work, and the Grantham are said to be the largest oil motor works in the world. The engines are built for many special purposes; a "Military Tractor" is one of the latest developments. At the Cambridge Show in 1894 two were exhibited, and were much commended for steadiness in running. The results of the trials will be found in the Table of Tests.

Trusty (1891).—A different method of vaporising the oil has been adopted in the Trusty engine, brought out by the Trusty Engine Works, now made by the Shillingford Engineering Co., Cheltenham, and resembling the gas engine of the same name, with the addition of an apparatus for volatilising the oil. Several years ago an engine was invented by Mr. Knight of Farnham, in which the oil was vaporised in a jacket round the combustion chamber. The patent of this engine was acquired by the makers of the Trusty, who have improved the principles of the early motor. In the Knight engine, ignition was obtained by making a flame, produced by the action of bellows, play at the right

moment upon a coil of platinum wire. In the Trusty, the charge was at first fired by directing an air jet upon an oil flame, but this method has now been abandoned in favour of ordinary tube ignition.

The engine is made single-acting, horizontal, with one or more cylinders; the action is similar to that described in the Trusty four-cycle gas engine. Fig 138 gives an end view, with the method of introducing the oil into the vaporiser. The latter, shown at V, consists of a jacket fitting round the combustion chamber at the compression end of the cylinder, and divided internally into sections. The air admission and exhaust valves S and S¹ are worked by levers L and L¹ from a shaft geared to the main shaft in the proportion of 2 to 1; in the latest engines the valve box is at the side of the cylinder, and there is a small air pump. At O O¹ are the screws for adjusting the valves; the exhaust outlet is at E. The oil is drawn through the pipe *p* from a tank below the engine, and pumped from the horizontal pump P through the second pipe p^1, into the column or receiver C at the top of the engine. From here it passes into the jacket or vaporiser V through a small glass tube above the cylinder, through which it is admitted drop by drop into V, where it is immediately vaporised, and passes through the vapour valve H to the combustion chamber.

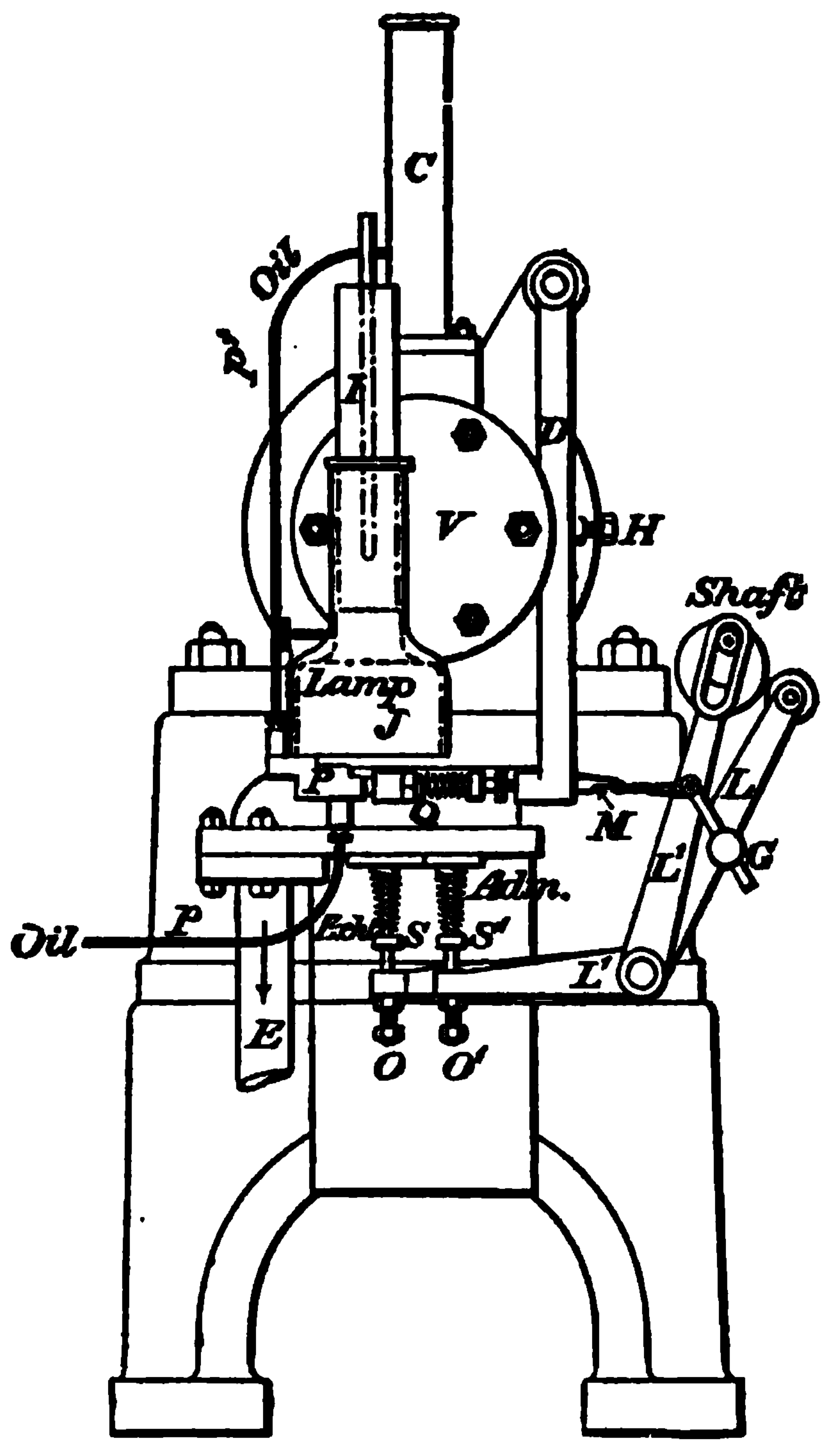

Fig. 138.—Trusty Oil Engine. 1891.

The quantity sent to the cylinder is regulated by the stroke of the oil pump, which in a 4 H.P. engine is about $\frac{1}{4}$ inch diameter. The igniting tube I is at the back of the cylinder and evaporating chamber, and is maintained at a red heat by a lamp J with blow flame. It is the heat of the inner wall, separating the vaporiser jacket from the combustion chamber, which vaporises the oil, except at starting, when a lamp must be used to heat it, and a few drops of oil pumped in by hand. The rod Q, actuating the oil pump P, is worked at M by a hit-and-miss device, controlled by the inertia governor G. If the speed is too great, the projection on the governor

cannot reach the notch on the valve-rod in time, a lever D is interposed, and the oil pump does not work. The lever also acts upon the valve H, admitting the oil to the cylinder, and the supply is thus doubly checked by the governor.

As the combustion of the charge takes place in the compression chamber, the jacket round it becomes so hot that the oil, as it enters, is instantly turned into vapour. The out-stroke of the piston draws in a charge of fresh air through the valve S^1, and at the same moment, through valve H, the vaporised oil is admitted into the compression chamber from the jacket. The oil vapour and air mingle in the cylinder, are compressed by the return stroke of the piston, driven up the tube, and ignited in the ordinary way; explosion and expansion of the charge follow. The parts and passages being easily accessible, the occasional cleaning required is carried out without difficulty. Broxbourne lighthouse oil, distilled from Scotch shale, with flashing point 150° F. and specific gravity 0·81, is usually employed in this engine, but a much heavier oil with flashing point 240° F. may be used.

Fig. 139.—Trusty Oil Engine—Indicator Diagram.

In a trial made by Mr. Beaumont on an engine giving 6·00 B.H.P. and 7·00 I.H.P. the consumption was 0·82 lb. oil per B.H.P. and 0·69 lb. per I.H.P. hour. The heat efficiency, taking the B.H.P., was 16 per cent., mechanical efficiency 86 per cent. In the 4·63 B.H.P. engine shown at the Cambridge trials, the consumption was 1·19 lbs. per B.H.P. hour. Particulars of these and other tests will be found in the tables. Fig. 139 gives an indicator diagram of the engine. The makers' types range from 1½ to 40 B.H.P. single cylinder, or two cylinders side by side, horizontal; the larger sizes are provided with a self-starter. Portable engines are made from 3½ to 20 B.H.P. The Trusty has also been adapted for propelling road carriages, and for oil launches. The speed of the engine is from 300 to 160 revolutions per minute.

Roots.—The original type of this engine was described in *The Engineer*, September 30, 1892, but the design has since been improved. It is now used almost exclusively for propelling motor cars, and as the Roots-Vosper launch for marine work. For the latter class of engine it is made with four cylinders, set diagonally in pairs, and a vaporiser to each set of cylinders. A lamp heats the vaporisers and ignition tubes, and the products of combustion are led through the combustion chamber round the vaporiser before they are allowed to escape. The supply of oil is pumped into two small tanks with glass sides, above the cylinders.

The vaporiser consists of a cylindrical chamber containing a series of spiral spaces, through which the air for vaporising the oil is drawn by the suction of the piston, and heated in its passage to the oil valve. The exhaust and the small horizontal oil pump are worked by a cam and lever from the side shaft. The latter carries a reciprocating spindle with one or more grooves, which are filled with oil each time the stroke of the pump sends the spindle into the oil chamber. During the return stroke it is brought in contact with the current of heated air from the vaporiser jacket, which sweeps off the oil from the grooves, and carries it on as spray to the chamber. Here it is completely vaporised by the heat and the force of the air blast, and mixed with a further supply of heated air as it passes to the automatic admission valve.

A ball governor acts on the spindle of the oil pump, and determines the number of grooves entering the oil chamber to be filled at each stroke, and hence the quantity of oil presented to the air current and evaporated. To reduce the speed the supply of oil can be cut off from one cylinder. In starting the engine three cylinders are thrown out of gear, and an explosion produced in one cylinder only. The propeller shaft is reversed by friction coupling for going astern. A 7 B.H.P. Roots engine was exhibited at the Cambridge Show, in which the oil consumption was 1·68 lbs. per B.H.P. hour. The author tested an engine of the same size, and found the consumption of oil 1·1 lbs. per B.H.P. hour; the heat efficiency per B.H.P. was 12·4 per cent.

Crossley-Otto.—The Otto may truly be called the prototype of all modern gas engines, and to its many advantages has been added that of working with petroleum. The oil motor introduced by Messrs. Crossley does not differ much from the Deutz-Otto, described among the German petroleum engines. It has a timing valve and tube ignition. The oil is drawn from a tank, and delivered to the vaporiser by a small pump, in quantities exactly proportioned to the power required. This pump, which is worked by an eccentric on the side shaft, has two plungers, which force oil from the tank at a pressure of 25 to 40 lbs. per square inch. One plunger sends it to the lamp heating the ignition tube and vaporiser; from the other a certain quantity is delivered to the measurer, and sent on to the seat of the air admission valve; the overflow passes back to the tank. The air enters through small holes above the chimney, through which the products of combustion escape. The suction of the piston draws it down through baffle plates, together with a measured charge of oil, into the vaporiser, where both are converted into oil spray, and thence swept into the cylinder. The admission valve is so arranged that air only first enters, the further motion of the

valve opens the little oil valve, and finally air alone is admitted. The exhaust and the vapour valve are worked from the side shaft, and the governor acts on the latter on the "hit-and-miss" principle. If the speed is too high, a small push piece misses a projection on the lever operating the vapour valve, and no charge is admitted.

As in many other oil engines, the lamp is an important feature. It is fed with oil under pressure from a small pump, charged by hand once or twice a day. In the latest engines an "Etna" lamp is used, in which a small jet of oil from the pump is converted into oil vapour, and burns with a clear blue flame on coming in contact with the outer air. The flame is directed on to the vaporiser and ignition tube, the latter being protected by a shield. In the smallest sizes the lamp is used only at starting, the heat of the explosions being afterwards sufficient to fire the charge. The consumption of the engine exhibited at Cambridge, which gave 7·3 B.H.P., was the lowest recorded, 0·82 lb. per B.H.P. hour, and it was much commended. Messrs. Crossley make their engines horizontal, in sizes from 1½ to 50 B.H.P. for ordinary work, and from 3½ to 54 B.H.P. for electric lighting, with a speed of from 350 to 200 revolutions per minute. A 15 B.H.P. portable engine was the best at the Cardiff Agricultural Show in 1901. The water for cooling the cylinder was contained in a tank, and circulated continuously, being broken up into spray by a current of air induced by the exhaust gases.

Griffin (1892).—This four-cycle oil engine, brought out by Messrs. Griffin, of Bath, must be distinguished from the Griffin gas engine formerly made by Dick, Kerr & Co., of Kilmarnock. The original type was single cylinder, horizontal, the admission and exhaust valves being driven from a side shaft geared to the crank shaft in the usual way. This is one of the few engines in which the oil is sprayed for the charge. The vaporiser is placed in the engine bed, below and at right angles to the cylinder. The spray is formed by a blast of air compressed in a pump to 12 lbs. per square inch, which opens the oil valve, sucks up the oil as it issues, draws it by induction up a diagonal tube, and carries it as fine spray into the vaporiser. Here the oil is converted into vapour by the heat of the chamber, which is ribbed internally, and surrounded by a passage for the circulation of the exhaust gases. Much of the heat of explosion must pass into this chamber. As the oil vapour emerges at the other side of the engine, it is carried to the cylinder above, and mixed in its passage with more heated air, to form an inflammable charge. It is said to be so highly explosive that it must be mixed with the exhaust gases, to prevent premature ignition. The charge then enters the cylinder, and is ignited by a tube uncovered by a timing valve, and maintained at a red heat by an oil spray Bunsen flame in

the following way:—A small quantity of oil trickles from the tank to a little vessel, is drawn upward by capillary attraction, broken up into spray by a blast of air from the pump, and carried forward into a pipe kept at a high temperature by the heat from the burner. Here it is vaporised, ignited at the Bunsen burner, and the flame plays continually on the tube.

Much importance is attached by the maker of this ingenious engine to the treatment of the oil in the cylinder. If the temperature in the vaporiser is too high the oil will be gasified, "cracking" takes place, and tarry products, which are difficult to burn, are formed. Therefore, when the exhaust opens, combustion is often incomplete. To avoid these difficulties, and to ensure the perfect vaporisation of the oil at a relatively moderate temperature, Mr. Griffin has lately brought out a "Hydro-oil" engine, resembling the original type, but with the addition of a small quantity of water to the oil forming the working agent. A charge in definite proportions of oil and water is atomised and thoroughly mixed by a blast of air which, at a pressure of 15 lbs. per square inch, carries it into the vaporiser. Here, as in the earlier engine, it is further mixed with air previously heated by the exhaust gases. The same pump supplies the oil, water, and air blast. The suction stroke of the engine opens the air valve to the atomiser, and the current of air lifts the oil and water valves, instantly converts the oil and water into mist, and sweeps them into the innermost of the three concentric chambers of which the vaporiser consists. Around this space is a jacket for the exhaust gases; the outermost chamber contains air for forming the explosive charge. With this system of vaporisation combustion is said to be complete, and no deposit is left in the cylinder. As the charge contains a certain amount of water gas, electric ignition is too uncertain, and tube ignition is used. The governor acts on the "hit-and-miss" principle, by suppressing the admissions, and varying the number of impulses.

For starting the smaller sizes of this engine the air pump is worked by hand, the oil spray thus formed is ignited, and in ten minutes the vaporiser is said to be sufficiently hot to work. An 8 H.P. stationary Griffin engine was exhibited at Cambridge by Messrs. Samuelson, of Banbury. The Griffin Engineering Company, Bath, have applied it successfully to a launch. The motor is vertical, with two cylinders and one crosshead, giving one impulse per revolution. It is started by releasing the flywheel, which is then rotated rapidly by a hand wheel, until sufficient impulse has been communicated to make the engine draw in a charge. The difficulty of reversing the motion of the ship has been overcome by having a left-handed and a right-handed screw, and coupling the motor shaft to one or the other as required. A two-

cylinder "Duplex" Griffin engine of this type has been fitted to a barge 72 feet long; the engine develops 35 H.P. It is made vertical, two-cylinder, in sizes from 5 to 100 H.P. Drawings of the original type will be found in *Engineering*, November 4, 1892.

Rocket (1893).—This engine, made under Kaselowsky's patent, was brought out by Messrs. R. Stephenson, of Newcastle, but is now no longer made. A trial was carried out in 1895, by Professor Robinson, on a 7·26 B.H.P. engine, in which the consumption of American oil was 0·86 lb. per B.H.P. hour, and the speed 200 revolutions per minute. A description is given in *The Engineer*, May 5, 1893.

Fielding (1894).—The oil engine brought out by Messrs. Fielding & Platt, of Gloucester, is similar to their gas motor, with the addition of a vaporiser. The method of vaporising the oil is ingenious. The combined vaporiser and igniter are contained in a chamber forming a prolongation of the cylinder, and consist of two horizontal tubes, one above the other, connected by the vapour valve, and two copper tubes above it, for heating the air. Both are heated by a blast oil lamp, the lower tube, in which the charge is ignited, being brought to a cherry-red, and the upper to a dull-red heat. A jet of oil is sent by a little pump with adjustable stroke into the upper tube, together with a small current of air previously heated by the lamp. The two pass through a valve into the lower igniting tube, the heat of which ensures complete vaporisation, and thence to the cylinder, where, to render the charge explosive, they are mixed with more air entering through an automatic valve. The next compression stroke drives them back into the lower ignition tube, which is open to the cylinder without a timing valve; the charge is fired and the cycle completed. The lamp is fed from a small separate reservoir, the pressure in which is maintained, and the oil raised for the lamp, by means of a hand pump at starting. As soon as the engine is at work, the piston during the exhaust stroke uncovers a small port opening to the oil receiver, and the pressure of the exhaust gases is utilised to force a small portion of the oil into the tube leading to the lamp, which is thus fed automatically. The admission and exhaust valves and oil pump are driven by cams from the side shaft, and acted on by the ball governor. If the normal speed is exceeded, the exhaust is held open, the supply of oil cut off, and the automatic air admission valve is closed by the fall in pressure. Thus there are no explosions, and all the valves are thrown out of gear. The makers consider that ignition is more certain if the vaporiser is heated by a lamp, than if the internal heat of the engine alone be relied on to raise the temperature, but for small powers the lamp can be dispensed with. The engine is made in sizes from 1½ B.H.P. upwards, horizontal, both portable and stationary, and runs at 350 to 190 revolutions per minute. The consumption is said to be a little less

than 1 lb. oil per H.P. hour. An 8 B.H.P. motor was exhibited at the Cambridge Oil Engine Trials.

An interesting development is a 70 H.P. Fielding oil engine, lately built for the General Electric Co., to supply electric light in the palace of the Emperor of Korea. There are two cylinders opposite each other working on to separate crank pins, with a piston speed of 800 feet per minute. All the parts are in duplicate, each cylinder having its own valve gear, governor, and side shaft. The "hit-and-miss" governor acts as already described. The two oil pumps draw from suction vessels, in which the oil is at a constant level, and deliver it under slight pressure to the vaporiser. The engine is started by compressed air supplied to one cylinder till the other begins to work. The dynamo is driven by a belt from the flywheel, but can be directly coupled, if desired.

Robey-Saurer (1894-1904).—The Robey oil engine was shown at Cambridge in 1894, and at Darlington in 1895. It is similar to the four-cycle gas engine of the same makers, with the addition of a vaporiser, and embodies some of the latest improvements in oil engines, which all tend in the direction of greater simplicity. There is no side shaft; the levers working the valves are above the cylinder, and all the parts are easily accessible. Heavy petroleum is generally used in this engine, with a flashing point of 240° F. It is drawn from a tank in the base by a small oil pump worked by an eccentric, pumped into an accumulator, and thence to a trip box. The governor on the crank shaft actuates the lever and spindle of the trip box, and sends on a small quantity of oil drop by drop, as required, to the vaporiser. In order that there may always be a sufficient supply of oil to the cylinder, the pump delivers more to the accumulator per stroke than is drawn from the trip box, the excess being sent back to the reservoir; thus a steady pressure is maintained by the accumulator in the oil valve or trip box. The combined vaporiser and igniter are placed in the centre of the combustion chamber, at the back of the cylinder. Behind them is the exhaust valve, the air admission is immediately below the vaporiser, and both valves are worked by cams and levers from a half-speed shaft above the crank shaft. The products of combustion pass through the vaporiser before they are discharged, and combine with the heat of the explosions to keep it at a high temperature. When the oil is delivered to the vaporiser the air valve is lifted, a supply of air heated by passing through the base of the engine enters, and mixes with the vaporised oil to form the charge. The next compression stroke drives them back into the vaporiser, which communicates with the cylinder through a narrow opening. The charge is fired, and explosion takes place not only within the vaporiser, but outside in the combustion chamber. The return stroke drives out the products of combustion through the chamber, thus sweeping it clean, and keeping it

free from tarry deposit. The exhaust valve and explosion chamber are water jacketed, as well as the cylinder, but have a separate drain pipe. The vaporiser and ignition tube are both kept hot by a simple automatic lamp, which when once started requires no further attention. The makers prefer this method to the system of heating the vaporiser by the heat of the explosions only, and they claim that the engine works equally well at almost any load. The ball governor acts through a hit-and-miss arrangement on the oil pump, and throws it out of gear if the normal speed is exceeded. The engine is made horizontal, single cylinder, stationary, in sizes from $1\frac{1}{2}$ to 50 B.H.P., portable from 7 to 14 B.H.P., and runs at 450 to 180 revolutions per minute. The larger sizes are started by compressed air; piston speed 450 feet per minute. The consumption of oil is about $\frac{3}{4}$ lb. per B.H.P. hour. One of these engines has been used to propel barges.

Premier (1894).—In this engine, made by Messrs. Wells, of Sandiacre, all the valves, as well as the governor and oil pump, are driven by one cam from the side shaft, which actuates a vertical rocking lever, held in position by a strong spring. The lever opens the exhaust and admission valves, while a link from it works the oil pump. The top of the lever terminates in a knife edge, and the governor consists of a simple horizontal bar above it, balanced on a pivot in the centre, with a notch at one end, and weighted at the other, furthest from the lever. At ordinary speeds the spring keeps the lever in position, the exhaust is closed, and the admission valve opened, at the right moment, and the knife edge is clear of the notch. If the number of revolutions is increased, the horizontal bar does not rise in time, the notch is caught, the movement of the lever arrested, and consequently all the valves are thrown out of gear. The exhaust remains open, and no charge enters the cylinder, or is sent to the oil valve. The vaporiser is a separate chamber at the back of the cylinder, heated, as well as the ignition tube, by a lamp; the latter is fed by a blast of air from a pump, worked by an eccentric from the side shaft. The oil runs from a receiver above into the oil valve box. Here a fixed quantity is measured into a small cavity in the plug of the rotary oil pump, which is driven by the link off the rocking lever. As the plug turns, the oil is discharged on to a hot slanting iron plate, and is vaporised as it runs down. A small quantity of air from the pump sweeps over the inclined plate, and carries off the oil with it; the two enter the combustion chamber in a tangential direction. The opening of the admission valve induces another current of air through the vaporiser, which sucks the oil vapour into the cylinder. Thus, in accordance with the latest views, the oil is not sprayed or broken up, but dropped in a liquid condition into the vaporiser. Heavy oil, Russian or American, can be used, and as the oil is

vaporised in minute quantities as required, its density is a point of no importance.

This oil engine is made single cylinder, horizontal, in sizes from 2 to 15 B.H.P., and runs at 260 to 200 revolutions per minute. A 6½ B.H.P. motor was exhibited at Cambridge, and was commended for the simplicity of the working parts. A test of the engine was made by Professor Robinson in 1895.

Tangye.—It would be difficult to design a simpler oil engine than the Tangye, introduced in 1895. There is no pump, fan, or storage

Fig. 140.—Tangye Oil Engine.

of oil or air under pressure, and only two valves for admission and exhaust. The inlet valve is automatic, the exhaust is worked by cams from the side shaft. A peculiar feature is that the oil is not perfectly vaporised when it enters the cylinder, but only becomes so when driven back during the compression stroke into the hot vaporiser and combustion chamber. Any ordinary oil can be used. From a small tank above, containing sufficient for a day's supply, the oil runs by gravity to the admission valve, the quantity per stroke being adjusted automatically. The suction of the piston draws it, together with a current of air at high pressure, through the admission valve to the vaporiser, which is placed between the cylinder and the hot ignition tube. At starting the vaporiser is heated by a small wickless oil lamp, but as soon as the engine is at work the lamp is shifted beneath the ignition tube, and the proximity of the

tube, and of the cylinder, to which the vaporiser is always open, is sufficient to keep it at a high temperature. The oil, already partly mixed and vaporised, is carried forward with the air into the cylinder, the next stroke sends the charge back through the vaporiser, where it is finally converted into vapour, to the ignition tube, communication with which is opened by a timing valve, worked from the side shaft, and the cycle is then completed. The centrifugal governor acts by holding the exhaust open and the admission valve closed, thus checking the supply of both oil and air to the cylinder. The temperature in the latter is regulated by opening or closing the air jacket round the vaporiser, and also the chimney over the ignition tube. The engine is made horizontal, single cylinder, in sizes from 2½ to 45 B.H.P., and runs at 180 to 320 revolutions per minute. The consumption is about 0·8 lb. oil per B.H.P. hour. Fig. 140 gives a general view. Messrs. Tangye also make engines to work with benzine, alcohol, and petrol, and a vertical marine type has lately been brought out.

Howard.—An oil engine of the ordinary Otto cycle type, especially intended for agricultural purposes, was brought out in 1895 by Messrs. Howard, Brothers, of Bedford. The oil is drawn from a tank in the base of the engine, and delivered to the vaporiser through a nozzle by a small oil pump, worked by a cam and lever from the side shaft. A small current of air is drawn in at the same time, sufficient to break up and spray the oil, but not to render it inflammable. The vaporiser at the end of the water-jacketed combustion chamber is in three divisions, the centre being the hottest, and is heated by a lamp, which also serves to maintain the ignition tube at a red heat. The oil for this lamp is fed from a separate receiver, into which it is forced by a pump, of which there are two, supplying oil both to the vaporiser and to the lamp. The surplus is returned to the tank. The already vaporised oil passes to the admission valve, and thence to the combustion or mixing chamber, where it is diluted with the main supply of air, drawn in through an automatic valve at the side of the engine, and the two are swept into the cylinder, compressed and ignited in the usual way. Communication between the vaporiser and combustion chamber is shut off by the admission, or as it is sometimes called the vapour valve, except during the injection of oil. There is no timing valve to the tube except in large power engines, the moment of ignition being determined by the length of the tube. The two valves regulating the supply of oil to the vaporiser, and the admission of the charge to the cylinder, are both controlled by the ball governor, on the hit-and-miss principle. The heat of the lamp vaporises the oil supplying it. Compression of the charge is from 35 to 45 lbs. per square inch; the mean indicated pressure in an 8 H.P. engine was from 78 to 90 lbs. per square inch. The Howard engine is made stationary

in sizes from $2\frac{1}{2}$ to 16 B.H.P., and portable from 4 to 16 B.H.P., and runs at a speed of 300 to 200 revolutions per minute. In the portable engines the circulating water is cooled by a special arrangement of the water tank.

Clarke, Chapman & Co.—The oil engine formerly made by this firm on Butler's patents was similar in design to their gas engine, with the addition of a vaporiser. It had a circular balanced rotary valve driven from a valve shaft, and revolving at one-quarter the speed of the engine. The vaporiser was a chamber having two concentric spaces, one within the other, the exhaust gases from the engine being carried into the hollow central space, and thence discharged. The heat thus obtained was sufficient to vaporise the oil, which was further broken up by hot air drawn in by the action of the engine. A second supply of air, sucked in automatically through a nozzle by the piston, was mixed with the oil vapour on its way to the cylinder, and the inflammable charge was then treated in the same way as in the Clarke-Chapman gas engine. The speed was regulated by a throttle valve on the supply pipe, acted on by the governor. The charge was fired by electricity. In a test made at the works at Gateshead on an engine developing $11\frac{1}{2}$ B.H.P., the charge was compressed to 45 lbs., and the maximum pressure of explosion was 165 lbs. per square inch. A 6 B.H.P. stationary, and a 12 B.H.P. portable engine were exhibited at Cambridge, and were the only motors using electric ignition. The consumption in the portable engine was 1·25 lbs. oil per B.H.P. hour. A 14 B.H.P. portable engine was exhibited at the Darlington Agricultural Show in 1895. Some of the later engines were made to run interchangeably with oil or gas, but their manufacture has now (1904) been given up.

Clayton & Shuttleworth.—It is claimed for the engine made by this firm under Knight and Weyman's patents that it will work with any oil, however heavy, and even with Broxbourne shale oil of 240° F. flashing point. The motor is of the ordinary four-cycle single-cylinder type, with mushroom valves worked from a side shaft in the usual way. The oil is drawn from a tank, and sent to the vaporiser through a glass sight feed tube by a small oil pump. The vaporiser is simply an extension in the shape of a jacket at the back of the cylinder, and is said to vaporise the oil thoroughly, without deposit, and without requiring an air blast to break it up. It is fitted with a vapour or admission valve, through which the oil vapour passes to the cylinder, where it is mixed with air drawn in through a separate valve driven by a cam on the valve shaft. The patent igniter consists of a very small cast-iron tube containing a steel needle surrounded with asbestos, which is placed horizontally inside the vaporiser and combustion chamber, and open to the cylinder. After the first few strokes the heat of the explosions is

sufficient to maintain this inner tube at a red heat, and it fires the charge at the end of the compression stroke. Beneath the vaporiser is an ordinary ignition tube, which at starting is brought to a red heat by means of a lamp below it. The latter is in the form of a tray, on which several burners are placed, and connected to a petroleum reservoir. As soon as the engine is at work the lamp is extinguished, the hot tube shut off, and the charge then fired automatically by the igniter. In this engine, as in the Hornsby, the compression space can be varied in size, to suit different kinds of oil. Russian petroleum requires more compression than American, and this is obtained by screwing plates on to the end of the piston, of thicknesses varying from $\frac{1}{2}$ to 1 inch. The pendulum governor acts both upon the oil pump and the vapour valve, and the quantity of oil admitted to the cylinder is regulated according to the load. Larger sizes of the engine are started by a self-starter, a reservoir into which part of the explosive charge is previously compressed, and admitted to the cylinder through a special starting valve. Trials were made on a 6 B.H.P. motor in 1893, and showed a consumption per B.H.P. hour of 0·82 lb. of oil of 0·80 density, and 19,500 T.U. heating value. The mechanical efficiency was 85 per cent., and heat efficiency 16 per cent., a good result for so small an engine. The low consumption showed that the oil was more or less completely vaporised. Similar results were obtained in a later trial. The engine is made horizontal, single cylinder, in sizes from $1\frac{1}{2}$ to 24 B.H.P., with a speed of 260 to 200 revolutions per minute, and a piston speed of about 700 feet per minute.

Campbell.—This is a four-cycle oil engine of the Otto type, resembling the gas engine by the same makers, with the addition of a vaporiser. Like most of the latest English petroleum motors it is very simple in construction, having no pump; there are only two mushroom valves, inlet and exhaust. The oil flows by gravity from a tank above to a small supply pipe, terminating in two fine holes round the automatic admission valve above the vaporiser. The suction of the piston during the out-stroke draws down this valve, a current of air enters from above, and a minute quantity of oil through the holes at right angles to it. The oil is broken up by the inrush of air, and sprayed by being projected against the sides of the valve chamber. The two then pass to the vaporiser below, which, with the ignition tube, is contained in a chamber at the side of the cylinder, and kept at a red heat by the flame of a lamp. The exhaust, worked by an eccentric on the crank shaft, is at the back of the engine. The oil already sprayed is vaporised by the heat of the chamber, and the charge passes to the cylinder; the next compression stroke drives it into the ignition tube, where it is fired in the usual way. When the engine is worked at full load the lamp can,

after a short time, be dispensed with, the vaporiser being hot enough to vaporise the oil, and fire the charge. The ball governor on the side shaft acts on the "hit-and-miss" principle on the exhaust, and holds it open if the normal speed is exceeded. As there is no vacuum in the cylinder, the automatic admission valve does not rise, and no air or oil can enter. A 4 B.H.P. motor was exhibited at the Cambridge trials, and consumed 1·12 lbs. oil per B.H.P. hour. The engine is made horizontal, single cylinder, in sizes from 1 to 45 B.H.P. for fixed, and 3½ to 17 B.H.P. for portable engines, and vertical from 1 to 4 B.H.P., and runs at 270 to 150 revolutions per minute. A vertical two-cylinder type is also made for boats, from 2½ to 15 B.H.P.

In the portable engines the cooling water is forced, as it leaves the cylinder jacket, into a vessel, where it is sprayed on to a series of plates. The exhaust gases are utilised to create a current of air through the cooler, in the reverse direction to the falling water. The engine has also been used for mining work, and a searchlight plant has lately been supplied to the War Office, in which the same method of water cooling is employed. The temperature of the water on leaving the jacket is 180° F., which is reduced in the cooler to 85° F., and 48 gallons of water are sufficient to work a 10½ B.H.P. engine for ten hours. An interesting account of a 10 H.P. Campbell oil engine, used on a sugar estate in the Colonies for towing barges, will be found in *The Engineer*, April 19, 1901. Steam propulsion was impossible, because of the soft mud forming the banks of a narrow canal, along which the barges had to be conveyed. A stationary Campbell engine was, therefore, mounted on a punt, and a rope taken forward along the bank by men for half a mile. It was then made fast, the engine started, and the punt was drawn along by hauling in the rope, while paying out another rope attached to the barges. The end of the rope being reached, the punt was moored, and the engine drew the barges along by driving a drum on the punt, over which the hauling rope was coiled.

In a careful trial made by Professor Stanfield in 1900 on a 14 B.H.P. Campbell oil engine, particulars of which will be found in the Tables, the consumption of oil per B.H.P. hour was 0·84 lb., and the thermal efficiency 16·2 per cent.

A full description of an engine made by the **Blaxton Engineering Co.** will be found in *Engineering*, June 29, 1900. It was shown at the Paris Exhibition, but does not appear to have retained its place in the market.

Kynoch-Forward.—In this engine, brought out in 1903, an ingenious attempt has been made to overcome the difficulty of pre-ignition, due to the high compression of the charge. If it is fired by electricity, this danger is minimised, but in oil engines, in which tube ignition is

mostly used, the inflammable oil vapour generated causes much trouble, especially if, to simplify construction, a timing valve is omitted. In the Kynoch-Forward engine, the difficulty of pre-ignition is said to be obviated, although there is no timing valve. The oil is drawn from a reservoir by the slight vacuum formed behind the piston, and passes into the vaporiser with a small quantity of air, not sufficient to ignite the charge. The ignition tube and an air valve, to admit the main supply of air, are placed between the vaporiser and the cylinder. During the return (compression) stroke the latter valve rises, a rush of cold air mingles with the compressed charge and forces it over the ignition tube, and into the vaporiser. The makers claim that the slight fall in temperature thus obtained is sufficient to prevent premature ignition. Between the vaporiser and the ignition tube is the vapour valve, on which the governor acts on the "hit-and-miss" principle, and no charge enters the cylinder if the normal speed is exceeded. The ignition tube is heated by a lamp at starting, afterwards only by the heat of explosion. In a test made on a 7 B.H.P. engine by Mr. Lea, the consumption per B.H.P. hour was 0·67 lb. of oil, having a net heating value of 19,740 B.T.U. per lb. Particulars will be found in the Tables. The engine is made in sizes from 2 to 35 B.H.P., and runs at 280 to 170 revolutions per minute, with a piston speed of 700 feet per minute.

Britannia.—A motor of their own design was brought out by the Britannia Co. of Colchester, and exhibited at Darlington in 1895. A drawing will be found in *Engineering*, Feb. 21, 1896. A new and well-designed type, on Nicholson's patent, has now been introduced. In this later engine the oil is contained in the base, from which it is drawn by the suction of the piston, as soon as the vapour valve admitting the charge to the cylinder has been opened by a cam on the side shaft. Air is admitted partly through the main air valve, partly through a small pipe communicating with the vaporiser, a ribbed chamber at the back of the cylinder. The oil is forced, through a tube fitted with a sleeve pierced by holes, into the vaporiser, in which baffles are fixed, to break it up in its passage. The amount admitted is regulated by a throttle valve in the air pipe, which determines the vacuum in the cylinder, and hence the quantity of oil drawn in per stroke. The charge is fired by a small hollow plug or igniter, ribbed internally and placed at the side of the vaporiser; it is heated by a lamp at starting, and afterwards maintained at a red heat by the heat of explosion. The out suction stroke draws part of the oil and air from the vaporiser through the plug, but the charge does not ignite till it is diluted with more air from the main air valve, and highly compressed by the return stroke. The hit-and-miss governor acts on the vapour valve, and wholly closes it if the load is increased. The automatic valves are not opened, and as no fresh charge

enters to cool the vaporiser and igniter, they retain enough heat to fire and vaporise the charge as before. Ignition is said to be certain because the igniter is always filled with rich gas, the composition of which does not vary, and it is here that the strongest explosion takes place. An ordinary plumber's lamp is used to heat the engine at starting, after which its action is practically automatic. Care is taken not to allow the vaporiser to attain such a temperature as would "crack" the oil. The engine is made horizontal only, in sizes from 1½ to 50 B.H.P., and runs at 320 to 160 revolutions per minute.

The **Midland**, formerly made by the firm of Taylor & Sons, whose business has been taken over by the Railway and General Engineering Co., Nottingham, is now no longer constructed. A description will be found in the Third Edition, p. 353.

The **Blackstone** is an oil motor of the ordinary Otto type, made by the Blackstone Company, Stamford, who have acquired Carter's patents. The vaporiser consists of three annular concentric passages, the outer forming a jacket through which air for the charge is drawn and heated; the middle is the vaporiser proper, while the innermost central passage contains asbestos, and acts as an automatic igniter. Oil is injected into the vaporiser from a reservoir in the base of the engine by a pump, the action of which is controlled by the governor. Air is at the same time drawn through the outer jacket into the vaporiser, where it meets and breaks up the oil, and the charge passes to the vapour or admission valve, and thence to the cylinder. The vapour valve, oil pump, and exhaust are all worked by cams from the side shaft. The speed of the engine is regulated by the centrifugal governor on this shaft, which, by means of a cam and a catch, acts on the oil pump to the vaporiser and the vapour valve, and cuts off the supply to both if the normal speed is exceeded. It is the compression stroke which forces the charge of oil and air back into the central igniting chamber, which is maintained at a temperature sufficient to fire the charge by the heat of explosion. The engine is made horizontal only in sizes from 2 to 60 B.H.P., with a speed of 300 to 150 revolutions per minute. Many hundreds are said to be at work. An external view is given at Fig. 141.

The **Globe**, made by Pollock, Whyte & Waddell, is an oil engine of the ordinary type, with mushroom valves mechanically driven, and hot-tube ignition. Petroleum flows by gravity from a reservoir above to a valve worked from the side shaft, and thence to the vaporiser, a circular chamber at the back of the cylinder, placed above the ignition tube, and heated by the same lamp. A small quantity of air enters through a little hole at the side, and helps to convert the oil into vapour. The two then pass through a "vapour" valve to the cylinder, being further diluted on the way by the main supply of air through another valve.

Fig. 141.—Blackstone Oil Engine.

If the normal speed is exceeded, the inertia governor acts upon the vapour and oil valves, and wholly cuts off the supply, and air only enters the cylinder until the speed is reduced. The engine is said to work well, but as the main supply of air is admitted cold, it must, to a certain extent, chill and condense the oil vapour, and, when the governor acts, cool the cylinder. The engine is made in sizes from 1 to 50 B.H.P., horizontal only, single cylinder, single-acting, and has a piston speed of about 500 feet per minute.

The **Cundall** is a well-constructed oil engine of the usual type, with hot-tube ignition and vaporiser, both heated by the same lamp. The oil is fed into the vaporiser through a cup, the capacity of which is varied by a valve acted on by the governor, and the supply regulated in accordance with the power required. It is admitted in such small quantities at a time that the whole is instantly vaporised and burnt, and there is said to be no waste. The vapour and exhaust valves are worked by cams, the air supply valve is automatic. The engine is started by hand, with the help of a second exhaust cam on the valve shaft. It is made horizontal only, from 2 to 80 B.H.P.; larger sizes, up to 300 H.P., are in course of construction. The portable engines are from 4 to 20 B.H.P., speed 280 to 160 revolutions per minute.

The **Ideal**, made by Messrs. Hardy & Padmore, is similar in construction to the Ideal gas engine, with the addition of a vaporiser. It is very simple, and no pumps for the oil and air are required. The flame of a blast lamp worked by hand is allowed at starting to play upon the ignition tube and vaporiser; the latter consists of a coil of pipes between the tube and chimney. The oil runs from a reservoir into a second receiver, and thence to a valve controlled by a pendulum governor through a rocking lever. The suction of the piston draws the oil into the vaporiser, where it is volatilised, and thence to the main admission valve. Here it is mixed with air through an inlet, the section of which is previously adjusted, and the two pass to the cylinder through a valve driven from the side shaft. If the normal speed is exceeded, the "hit-and-miss" governor wholly cuts off the supply of oil, and air only is admitted till the speed is reduced. It is claimed for this engine that it can be started in 1½ minutes. After running for a short time the lamp is extinguished, the valve leading to the ignition tube and vaporiser is shut off, and the engine works without either, the oil being vaporised and the charge fired by the heat of an iron vaporising plate fixed in the compression space. The Ideal is made in sizes from ½ to 5½ H.P., with a speed of 450 to 300 revolutions per minute.

The **Gardner** oil engine resembles the gas engine made by the same firm. It is a handy little motor, with hot-tube ignition, made to work with either petroleum or benzoline; sometimes the charge is fired electric-

ally. The engine carries no side shaft. There are two mushroom valves for exhaust and admission, both driven by rods and levers from the same eccentric. A cylindrical ram fits into the cylinder of the oil pump. The oil is fed in by gravity; the action of the ram as it is driven in by a rocking lever is to force out the oil through a nozzle into a small measuring cup, from whence it passes to the vaporiser. A screw on the lever adjusts the charge of oil by varying the stroke of the pump. The suction stroke of the motor piston draws the oil, together with a small quantity of air, through the vaporiser to the vapour or admission valve, where it is mixed with more air in the usual way. For a description of the air blast lamp heating the vaporiser and ignition tube, see the paragraph on lamps in Chapter xix. The air for it must be pumped in every hour. The engine is made in sizes from ½ to 20 B.H.P., and runs at from 450 to 190 revolutions per minute. The consumption is about 1 lb. oil per B.H.P. hour.

The **Nayler** is a simple engine of the usual Otto type, made chiefly for farm and agricultural purposes, pumping, &c., in sizes from 1½ to 25 H.P. The oil is contained in a small tank above the cylinder, and passes to the vaporiser through a sight feed cup, thus the supply may be regulated at will. The rotary ball governor acts on the "hit-and-miss" principle. When used as a portable engine, the circulating water is forced by a pump from the cylinder jacket on to a cone, where it is cooled by an induced current of air. An equally simple engine is made by Messrs. **Brown & May,** of Devizes, in which the oil passes from a receiver above the cylinder to the vaporiser. After the engine is started, the vaporiser is kept hot, and the charge fired by the heat of the engine alone, no external light being required. The rotary governor acts on a throttle valve in the oil pipe, and regulates the supply of oil according to the load. The inlet and exhaust valves are worked from the side shaft. The engine is made portable and stationary, in sizes from 1½ to 15 B.H.P.

An oil engine embodying several of the latest improvements is made by the **Newton Electrical Works,** Taunton. Of the two sets of valves, the exhaust only is worked by a cam on the side shaft, the admission valves are automatic. A carefully regulated quantity of oil is drawn from a tank in the engine bed by the stroke of the motor piston, together with a minute supply of air, into the vaporiser, a chamber at the side of the cylinder, through which the exhaust gases are led to heat it. The main air supply is sucked in through an automatic valve, and mixing with the vaporised oil carries it on to another automatic valve admitting the charge to the cylinder. The rotary ball governor on the side shaft acts upon this valve, and regulates the quantity of mixture passing through it according to the load, the proportions of the charge remaining the same. The vaporiser and an external ignition tube below it are heated

by a lamp at starting. As soon as the engine is at work, the lamp is withdrawn, the external tube allowed to cool, and the charge fired by an internal ignition tube, in the same way as in the Clayton and Shuttleworth engine. It is claimed for the Newton that by utilising the exhaust gases to heat the vaporiser, the temperature of the latter is regulated according to the work done by the engine. An increase in the H.P. developed increases the volume of the charge, and of the exhaust gases, which thus transfer more heat to the vaporiser, to counterbalance the larger quantity of cold air drawn in. The engine is made horizontal, in sizes from 1½ to 25 H.P., portable from 3 to 15 H.P., and runs at 340 to 190 revolutions per minute.

The **Ruston**, made by Ruston & Proctor, is another simple oil engine, with spontaneous or automatic ignition, differing from others chiefly in the method of vaporising the oil. The latter is drawn by a pump from the base of the engine, and sent to a small reservoir, from whence a minute quantity, carefully measured, flows per stroke to the vaporiser, a spiral coil placed in an extension of the combustion chamber, at the back of the motor cylinder. The oil is mixed on the way with a little air, and a further current meets it at right angles, and sweeps it into the vaporiser. The suction of the piston draws the charge thus formed through the vapour valve into the cylinder, where it mingles with the main supply of air, and is compressed and fired in the usual way. A small ignition tube fixed to the combustion chamber, and open to the cylinder without a timing valve, is maintained by the heat of the explosions at a temperature sufficient to ignite the charge at the end of the compression stroke. The vaporiser is surrounded by annular passages, and after being heated up at starting is hot enough, with the help of the heat stored up in these passages, to convert the oil supplied to it into vapour. The vaporiser and tube are heated at starting by a blast lamp fed with air from a small fan worked by hand. The centrifugal governor acts both on the small oil measurer regulating the quantity of oil delivered, and on the vapour valve. Any excess of oil is returned to the base of the engine. To start the motor, a roller attached to the exhaust lever pin is brought in contact with a projection on the cam shaft, and holds the exhaust open. The roller works along the pin, as the engine moves out, towards a smaller cam, and the opening of the exhaust is thus graduated till the engine is fairly started. The main supply of air can be varied by hand while the engine is working, and the richness of the charge controlled. Compression is adapted to suit the kind of oil used. The Ruston 12 H.P. portable engine was one of the best at the Royal Agricultural Show in 1901. The engine ran throughout the trials without a lamp, at about 220 revolutions per minute, the consumption of oil was 0·69 lb. per B.H.P. hour, heat efficiency 19·9 per cent. The water for

the jacket was circulated continuously in a cooling tower. The Ruston is made horizontal in sizes from 5 to 50 B.H.P., portable from 4 to 14 B.H.P., with a speed of 240 to 190 revolutions per minute.

In the **Capel**, a small vertical engine of 2 B.H.P., the oil is drawn from a reservoir into the vaporiser at the back of the engine by the suction stroke of the piston, controlled by the governor. The engine is said to work well, and the oil is completely vaporised. The charge is fired by electricity.

The **Dudbridge** is of the usual type, with vaporiser and ignition tube, both heated by a small automatic lamp. The vaporiser is external to the cylinder, and consists of an annular chamber surrounded by the chimney of the lamp. Outside this is a circular passage where a small quantity of air is heated, and admitted to the vaporiser with the oil, to break up and assist in volatilising it. The suction of the piston draws down the oil through a series of baffles, which are said to ensure its complete vaporisation; the main air charge is not added to it till it enters the combustion chamber. This air supply is drawn in through a valve driven by a lever from the crank shaft, and the same lever actuates the oil pump, which delivers a measured quantity of oil per stroke, and the vapour valve admitting the charge to the cylinder. The engine is made horizontal only, in sizes from 1 to 50 B.H.P., and runs at 330 to 170 revolutions per minute; for electric lighting from 1¼ to 65 B.H.P., at slightly higher speeds, and portable from 4 to 20 B.H.P. It has also been used in France to work a road roller. Two engines of 16 H.P. were supplied to a French firm for this purpose, and have been running successfully since 1900. Drawings and a description will be found in *The Engineer*, March 21, 1902. The consumption of heavy petroleum in the larger engines is about 0·75 lb. per B.H.P. hour.

Messrs. **Drake and Fletcher** have lately brought out a well-designed oil engine similar in type to their gas motor. It is of the usual four-cycle kind, with a vaporiser maintained, as well as the hot ignition tube, at a bright red heat by a fixed blow lamp beneath them. A given quantity of oil per stroke is conveyed from the base of the engine by a small oil pump driven from the side shaft, and the suction of the piston draws it into the vaporiser. Here it is converted into rich oil gas, and delivered to the cylinder, mixed with the proper proportion of air to render it inflammable. The return stroke of the piston compresses the charge in the usual way. The governor acts both upon the admission of oil to the vaporiser and of the charge to the cylinder, and wholly cuts off the supply if the normal speed is exceeded. The vaporiser is kept at a temperature of about 325° F. The air pressure to the blow lamp is about 20 lbs. per square inch. The engine is made horizontal, single cylinder, in sizes from 5 H.P., and portable from 7 H.P.

A four-cycle horizontal engine to work with ordinary petroleum is made by the **Acmé** Engine Company, of Glasgow. It is similar to their gas engine, described at p. 105, with the addition of a vaporiser.

The **Petter** is another simple engine, especially designed to drive pumps, and for agricultural purposes. The exhaust valve only is worked by gearing; the admission valve is automatic. The oil flows under pressure from a receiver above to the vapour valve, where it is atomised by a current of air drawn in by the suction of the piston, and further vaporised by the heat of the cylinder and of compression. There is no vaporiser, the oil being converted into gas in the cylinder itself. In the larger engines the exact quantity of oil required to form the charge is sent to the cylinder by a small pump. The governor acts both on the oil inlet and on a throttle valve in the air pipe, and regulates the admission of both according to the load, but the proportions are maintained uniform, and there is an explosion at every second revolution. Ignition is by a hot tube heated by a lamp at starting. This is afterwards extinguished, and the charge is fired by means of a second tube enclosed in a box surrounded by the exhaust gases, the heat from which suffices in a few minutes to bring it to the required high temperature. As the box protects the tube from contact with the cold outer air, its "life" is said to be considerably prolonged. The engine is made horizontal, in sizes from 2 to 34 B.H.P., and runs at 480 to 200 revolutions per minute; portable from 1 to 17 H.P. About a thousand have been made since 1896.

A description of the **Safety**, the **Thistle**, and the **Atlas** oil engines, none of which are now made, will be found in Chapter xx., 3rd edition.

CHAPTER XXI.

AMERICAN GAS AND OIL ENGINES.*

CONTENTS.—Westinghouse—Nash—Sintz—Foos—Webster—White & Middleton—Raymond—Pacific—New Era—Pierce—Springfield—Dayton—Wolverine—Fairbanks-Morse—Ruger—Vreeland—Backus—Star—Olds—Weber—Mietz and Weiss—Palmer—Warren—Grand Rapids—Otto Gasoline—Lawson—Racine—Climax—Wing.

THE gas and oil engines produced in America are, with the exception of the Westinghouse, neither so varied in type nor so numerous as in Europe, and this may be partly attributed to the low price of coal in the United States, which renders it unnecessary to seek any less costly motive power than steam. Cheap oil in large quantities is, however, obtained in Pennsylvania and other places, and within the last few years the construction of internal combustion motors, especially for large powers, has greatly increased. The following engines, representing the chief types made in the United States, are mostly intended to be driven either with gas or benzine (light petroleum), "gasoline," as it is called. Ordinary heavy petroleum is not much used in America to generate power in an engine, the lighter oils being preferred, as easier to handle, cheap, and abundant.

The **Westinghouse** engine, a full description of which will be found at p. 112, is made in America by the original firm, the Westinghouse Machine Company, of Pittsburg. It is much used to work with natural gas, of 1,000 B.T.U. per cubic foot heating value. With this rich gas the heat efficiency is said to be from 21 to 25 per cent. in engines of less than 50 H.P., and the consumption about 10½ to 12 cubic feet of gas per B.H.P. hour. The engine is specially intended for large powers of 1,500 H.P. and upwards, with several cylinders. Two engines of 1,500 H.P. each, with three cylinders 2 feet 10 inches in diameter by 5 feet stroke, have been made by the Westinghouse Company at Pittsburg. Many are in course of construction, or have been already erected, of 650, 280, 225, and 150 H.P., and hundreds are at work driven with natural or power gas. Among them is a large plant at Bradford,

* The editor has in this chapter had the assistance of Professor Hutton, of Columbia University, U.S., whose kind revision and valuable help are herewith gratefully acknowledged.

Pennsylvania, comprising one 200 H.P., and three 125 H.P. engines using natural gas, the consumption being 13 cubic feet per H.P. hour. Formerly the same gas was burnt under boilers to generate steam, and the consumption for the same power was 52 cubic feet per H.P. hour. In an electric station in Ohio there are a 650 H.P. engine, running at 150 revolutions, and a 280 H.P., with a speed of 280 revolutions per minute, both driven with natural gas, and generating electricity. Another station in Alleghany has two 125 H.P. Westinghouse gas engines, supplying power for three large cranes and other purposes. In New York State there are two 60 H.P. and two 90 H.P. engines, all worked with natural gas, and driving mills and dynamos, and twelve gas engines, with an aggregate of 3,000 H.P., in Kansas. When worked with power gas these engines are said to give 1 B.H.P. per hour per lb. of coal burnt in the producer. Oil is not suitable as the motive agent in these large power motors, but light oil, "petrol," or gasoline is used in engines from 10 to 50 H.P.

Nash.—As originally designed by the National Meter Company, New York, this was a vertical two-cycle engine, but this early type has been superseded by the usual four-cycle, with a side shaft, driven from the main shaft, and acting on the admission and exhaust valves through cams and rods. The admission valve-rod has an arm worked by the governor, which regulates the supply of gas according to the power required. The Nash engines are made vertical from $\frac{1}{3}$ to 10 H.P., and with two or four cylinders from 10 to 200 H.P.; for large powers they are much used for electric lighting and pumping. Either gas or gasoline may be employed as the motive agent.

Sintz.—This vertical engine is made in sizes from 1 to 15 H.P. by the Sintz Gas Engine Company, of Michigan. Like the early Nash engine and the Day* in England, it is a two-cycle motor; when driven by oil a small pump is added, worked from the engine. There are practically no valves, except one for admitting the charge. In the down stroke of the motor piston the exhaust port on one side of the cylinder is first uncovered, and next an inlet valve, through which air at a slight pressure is forced from the base of the engine. At the same time the gas valve driven by an eccentric on the crank shaft opens, and a charge of gas is sent into the compressed air, or if oil is used, the pump injects a small quantity of finely sprayed gasoline. The oil or gas and air strike against a deflector inside the cylinder, are forced upwards, and further compressed by the next up stroke. The charge is fired electrically at the dead point, contact being made by a connecting-rod worked by a cam on the crank shaft. The centrifugal governor acts upon the stroke of the pump, and diminishes the quantity of gasoline

* Described in the first edition of this work; p. 135.

in inverse ratio to the speed. A boat driven by a Duplex Sintz engine, with two vertical cylinders, was shown at Chicago in 1893. Motion was imparted by connecting the engine to the screw by a shaft and friction coupling, and a single handle served to regulate the quantity of oil passing to the cylinder, and the action of the screw in the water. The cooling water was sent to the cylinder jacket by a small pump driven from the engine, which was also used to pump out the bilge. A good many small marine engines of this type are made for lake and river work.

Foos.—A four-cycle engine, working with either gas or light petroleum (gasoline), is made by the Foos Gas Engine Company, Springfield, Ohio, both horizontal and vertical, in sizes from 2½ to 100 B.H.P. The motor is fired electrically, the connection and separation of the electrodes being effected from the main shaft through wheels. The light oil used requires little vaporising. It is contained in a tank at the side of the engine, and air, previously heated by passing round the exhaust valve, is drawn by the suction stroke of the piston through the petroleum vapour, which it absorbs in its passage to the admission chamber. The exhaust is worked by a connecting-rod passing through the base of the engine, and a cam on the valve shaft. The ball governor acts on the "hit-and-miss" principle, and cuts off the supply of gas or oil if the normal speed is exceeded.

The **Webster Manufacturing Company**, of Chicago, make engines both horizontal and vertical, driven either by gas or gasoline. They are of the usual four-cycle type, with admission and exhaust valves on either side of the cylinder, driven from a valve shaft running at half the speed of the crank shaft. The same shaft also actuates a small pump, which forces the gasoline from a receiver in the base of the engine, and sends it in minute quantities to a cylindrical chamber at the side. The air is drawn from the bed of the engine through the vaporiser by the suction of the piston, and passes, charged with oil vapour, to the cylinder, where the mixture is compressed, and fired by a tube heated by a Bunsen burner, fed with gasoline from a separate small tank. The centrifugal governor on the crank shaft throws the exhaust valve and oil pump out of gear, if the normal speed is exceeded. Many hundreds of these engines are said to be at work in the United States. They are made vertical, 2½ and 4 B.H.P., and horizontal from 4 to 28 B.H.P.

White & Middleton.—An engine of the ordinary four-cycle type, for gas or gasoline, is made by the White & Middleton Company, Baltimore, in sizes from 4 to 50 B.H.P. In this motor the valve shaft is replaced by spur-gearing. Ignition is by a tube with a timing valve, the spindle of which is worked from the motor piston. Ports are also

uncovered by the piston, through which part of the exhaust products escape; the remainder are discharged at the end of the stroke through a valve worked by a rod and levers from the crank shaft, through a slide and cam. The same rod actuates the spindle of the gas valve. Both exhaust and admission are thrown out of gear by the governor, if the normal speed is exceeded. If the engine is driven with gasoline, a small oil pump is substituted for the gas valve-rod, and is controlled on the "hit-and-miss" principle by the governor.

Raymond.—The vertical four-cycle Raymond gas engine is made by the Case Threshing Machine Company, Wisconsin, with one cylinder, in sizes from 1 to 20 H.P.; two cylinders, 4 to 50 H.P.; four cylinders, 60, 85, and 100 H.P. All the parts are enclosed in a cast-iron frame. The crank shaft is in the base; the latter also contains a reservoir of oil, into which the crank dips at each revolution. The rotary valves at the top of the cylinders are held on their seats by springs, and worked by spur gear from the crank shaft. The automatic ball governor on the flywheel regulates the quantity of the charge, but does not affect the proportions of gas and air, and the engine is said to work so well that there is scarcely 2 per cent. difference in speed when the load is thrown on and off. An impulse every revolution is obtained in the two-cylinder type; with four cylinders there is one impulse per stroke. The oil is drawn from a tank by a pump, and sent to a small glass reservoir above the vaporiser through a needle valve, controlled by the governor. Any surplus oil is returned to the tank. The air to the vaporiser is heated by the exhaust gases. The charge is fired by electricity, and the dynamos are worked direct by a strap from the flywheel. The engines are fitted with a patent starting device, and all sizes can be started with ease. A large number are made in the United States.

Pacific.—An engine of the ordinary four-cycle type, with electric ignition, and in which the motive power is derived from either gas or gasoline, is the Pacific, made by the Union Gas Engine Company, of San Francisco. It is especially adapted for marine work, fitted with reversing gear, and has a clutch lever for starting and stopping the propeller shaft. Water for the cooling jacket is drawn from and returned to the water round the boat. The engine itself is never reversed, but only the direction of motion of the propeller and secondary engine shafts. The exhaust valve is raised once in every two revolutions by a double-grooved cam on the crank shaft, into which a projection fits, in the same way as in the Daimler engine. The governor acts on the exhaust valve, and holds it open if the normal speed be exceeded. The vaporisation of the oil is effected by the force of an air blast. Air, previously heated by the exhaust gases, is drawn upwards

by the suction stroke of the motor piston into the vaporiser, a glass or metal chamber, above which is a tank containing light petroleum or gasoline. The current of air lifts a valve, and a small quantity of gasoline flows into the vaporiser, where it is said to be instantly turned into oil vapour by the hot air. The engine is vertical, and is made with two cylinders for large powers.

The **New Era**, so called, is a four-cycle engine, with valve shaft worked from the crank shaft by worm gear 2 to 1, and an exhaust port uncovered by the piston, in the same manner as in the two-cycle type. The ball governor is driven from the same shaft. The engine may be worked with lighting, natural, or power gas, or gasoline. With the latter a small pump is used, which draws a few drops of oil at a time from a tank, and forces them into the mixing chamber, where they impregnate the incoming air. The engine is made in sizes from 10 to 50 B.H.P.

The **Pierce** is another engine made to work with either gas or gasoline, of the ordinary four-cycle type, and built in sizes from 1 to 20 B.H.P. The side shaft drives the valves through a cam and connecting-rod. The governor, on the "hit-and-miss" principle, consists of a weighted steel finger like an inverted pendulum, which acts on the gas valve, and cuts off the supply if the normal speed is exceeded. Electric ignition is used, and the electrodes which produce the spark are arranged to rub against each other at every stroke, and are thus kept clean. Gasoline is supplied by a pump from an underground tank to a cup, from whence it passes to the air inlet valve, and any excess of oil is run back to the tank.

The **Charter** was one of the earlier four-cycle gas engines, and claimed to be the first to obtain power from gasoline, but its construction has now been given up. A description will be found in the Third Edition, p. 366.

The **Springfield** engine, which can be driven with any kind of gas—lighting, power, or natural—and also with gasoline, differs slightly from the usual type. Like the New Era it has an exhaust port uncovered by the piston at the end of its stroke, a method of construction usually found in two-cycle engines. It has also an exhaust valve which, together with the admission valve, is worked by cams from a horizontal shaft running across the top of the cylinder, and connected to a second longitudinal shaft driven from the crank shaft in the ordinary way. The governor worked from the crank shaft regulates the supply of gas and air according to the power required. If the engine is run with gasoline, a small supply pump worked by a cam on the longitudinal shaft draws the oil from a tank, and sends it on to a plunger pump, which regulates the quantity passing to the cylinder. If the oil flows by

gravity from an upper reservoir, no supply pump is needed. The charge is fired electrically. The engine is made horizontal in sizes from 1 to 40 B.H.P.

The **Dayton** gas or gasoline engine, made in sizes from 2 to 50 H.P., is of the ordinary four-cycle type, with electric ignition. The exhaust and admission valves are worked by cams from a valve shaft in the usual way, and the same shaft also carries cams driving the ignition rod for producing the spark, and the gas or oil valve. The centrifugal governor acts on the latter on the "hit-and-miss" principle.

The **Wolverine** is a small vertical engine made both four- and two-cycle, and using gasoline of 0·63 to 0·76 specific gravity. In the four-cycle type the exhaust is driven from a cam on the valve shaft, and the oil pump from an eccentric on the same shaft. The charge is admitted to the cylinder through an automatic valve. The engine is made single cylinder from 1 to 6 H.P., and with two cylinders up to 12 H.P. The two-cycle engine is somewhat similar to the Sintz. The up-stroke of the piston draws a charge of gas or gasoline and air into the enclosed base of the engine, and, at the same time, compresses the mixture already delivered to the top of the cylinder. At the upper dead point the charge is fired electrically, and the explosion drives down the piston. In its descent the exhaust port is first opened, and the burnt products discharged. The same stroke serves to compress the fresh charge below the cylinder through a passage at the side, from whence it passes through an open port in the cylinder head to the upper part, and the cycle recommences. As the port in the cylinder head is opened almost immediately after the exhaust, the incoming charge helps to drive out the exhaust gases. This two-cycle type is made for marine engines with one cylinder, up to 6 H.P., and for larger powers with two cylinders. Marine engines are fitted with reversing gear, which does not seem to present as much difficulty in America as in Europe, and the water circulating pump is driven by an eccentric from the crank shaft. The pistons of the two motor cylinders work alternately, the cranks being set at an angle of 180°. The gasoline is injected through a needle valve into the chamber enclosing the crank shaft.

The **Fairbanks-Morse** engine for gas or gasoline is based on the Caldwell. It is of the usual Otto cycle type, and is made horizontal from 3 to 70 B.H.P., and vertical 2 B.H.P. The motor has no side shaft. The exhaust valve is driven by a cam and roller from an eccentric on the crank shaft, and an arm from the valve-rod works the gas valve. The governor on the flywheel acts upon the exhaust roller, and throws it off the cam if the speed is too great. Air enters from the base of the engine, and passes with the gas to a mixing chamber, and thence through an automatic valve to the cylinder. The charge is fired

by electricity or hot tube; in the former case the spark is produced from the exhaust valve-rod. The engine is started from a reservoir of compressed air filled by hand. When driven with gasoline a supply is drawn from a tank in the base, and sent to a small reservoir. From hence a quantity, controlled by a small check valve, is forced through a nozzle into the air pipe by the current of air induced by the suction stroke of the piston, and the air and oil vapour pass in carefully regulated proportions to the mixing chamber.

The **Ruger** engine made at Buffalo is vertical, in sizes from 1 to 8 B.H.P., and horizontal from 10 to 50 B.H.P. It is of the ordinary four-cycle type, with a side shaft, and the governor acts by holding the exhaust open. The gasoline pump is also worked from the cam shaft. Ignition is by hot tube or electricity. In America the system of firing the charge in oil engines by spontaneous ignition appears to be seldom adopted.

The **Vreeland** is a small four-cycle engine for gas only, with a side shaft driving the exhaust and gas supply valves through cams. Communicating with the main exhaust is a supplementary exhaust valve, the object of which is to cleanse the cylinder more thoroughly of the burnt products during the return stroke. It is worked from the side shaft by a lever and cam. The governor acts on the gas valve, and wholly cuts off the supply if the normal speed is exceeded. The engine is made in sizes up to 20 B.H.P.

The **Backus** gas engine is made horizontal in sizes from 5 to 60 B.H.P., and also vertical for small powers. Like the Vreeland it has an auxiliary exhaust valve in the cylinder head, connected by a passage to the main exhaust ports, which are opened by the piston at the end of the out-stroke. The valves are driven from a side shaft geared to the crank shaft in the usual proportions, and which also drives the governor. The valve-rod for the subsidiary exhaust is worked by an eccentric from this shaft, and connected to the pendulum governor, which acts upon it if the normal speed is exceeded. In the vertical engine this eccentric is driven direct by a cam on the side shaft, while the governor acts on the gas supply. Gas and air enter the cylinder through the same valve, and pass from thence into a passage at the lower end, serving also for the discharge. In both types the bottom of the piston and of the cylinder are hollow, in order to obtain the maximum volume of the combustion chamber with the minimum wall surface.

The **Star** is another extremely simple motor, made horizontal from 1 to 25 H.P., and vertical 2 B.H.P. The admission valve is worked by a rod and cam from the reducing gear wheel, and contains an annular slot serving as a mixing chamber, through which both gas and air enter. The inertia or ball governor acts upon the rod, and regulates the

quantity of gas, either diminishing or wholly cutting off the supply, according to the power required. The exhaust on the other side of the cylinder is worked by an eccentric from the crank shaft.

The **Olds** engine for gas or gasoline also carries no side shaft. The valves are worked from an eccentric on the main shaft, the rod of which passes through a valve chest at the side of the cylinder. The exhaust valve is acted on by the pendulum governor through a ratchet and wheel, and is held closed if the usual speed is exceeded. The admission valve is automatic, the small oil pump is worked from the eccentric. Gasoline is pumped into a receiver at the top of the cylinder, above the admission valve, and the surplus returned to the reservoir, while air is drawn into the vaporiser from the engine frame by the suction of the piston, and the current pulverises the oil. The engine is also made two cylinder for launches and boats, in sizes from 2 to 8 H.P. The horizontal type is from 7 to 50 B.H.P., and the vertical up to 5 B.H.P. For marine work the water cooling the cylinder is discharged through the exhaust, thus reducing the temperature of the latter.

The **Weber**, a more important engine, much used for industrial purposes, is of the usual four-cycle type, made horizontal, and for powers of 2 B.H.P., vertical. A feature of the motor is the enclosed and water-jacketed valve chamber. Ignition is by a tube heated by a Bunsen burner. The valves are worked by three rods and cams on the reducing gear, serving the exhaust, admission, and ignition timing valves respectively. The cylinder cover, as well as the barrel, has a circulating water jacket. The governor acts upon the gas or gasoline supply, and varies the amount according to the speed, or wholly cuts it off, when the engine is running light. The gasoline is drawn from the tank, and supplied direct to the engine in a fluid state, no vaporiser being used. Nor does it come in contact with the air to form an explosive charge until it reaches the combustion chamber, and this contributes to the safety of an engine working with light oil. The principle differs wholly from the German method of admitting air to the oil twice, but the specific gravity of gasoline is much lower. There are two valves in the Weber to admit the gasoline to the cylinder; sometimes one of them is automatic. In the latest engines the exhaust ports are opened by the piston at the end of the outstroke, and a supplemental exhaust valve in the cylinder head is driven by a rod and cam. This is an arrangement seldom found except in American engines. The Weber is made horizontal, in sizes from 4 to 100 B.H.P., for electrical work, and especially for pumping and hauling in mines.

The **Mietz and Weiss** engine, made at New York, may be worked with natural or artificial gas, or kerosene. It is a two-cycle motor, with

an impulse per revolution. The crank and motor shaft are enclosed, and are cooled by a charge of fresh air through the crank chamber at each revolution. At starting, the charge is fired by a hot tube, but compression and the heat of the explosions are afterwards sufficient to produce automatic ignition. The oil is delivered by a small pump driven by an eccentric on the crank shaft. The centrifugal governor, also on the main shaft, rotates in accordance with the speed of the engine. It commands the plunger piston of the oil pump, which makes one stroke for every revolution of the governor shaft; thus the quantity of oil sent to the cylinder varies with the load. The oil is vaporised by a current of air drawn in at the dead point, and compressed by the return stroke to one-quarter its original volume. The engine is made horizontal, in sizes from 1 to 15 B.H.P., and runs at 500 to 300 revolutions per minute. It is much used for pumping and various industrial purposes, and also for marine work; in the latter type the action of the screw is reversed by friction coupling.

The **Palmer** engine is made two- and four-cycle by the Mianus Electric Company, Connecticut. In the vertical two-cycle type, constructed from 1½ to 6 H.P. for boats and launches, the crank and crank shaft are enclosed, and the cycle is similar to that already described in the Sintz and other engines. The charge is fired electrically. The four-cycle engine is of the usual type. At the end of the out compression stroke the piston uncovers a small port, allowing some of the burnt products to escape before the main exhaust port opens. The valves are worked from a side shaft, which also carries the centrifugal governor, and is geared 2 to 1 to the main shaft. The engine is made in sizes from 3 to 50 B.H.P., and has a speed of 250 to 160 revolutions per minute.

Two four-cycle engines for gas or gasoline, the **Warren**, made by Struthers & Wells, and the **Grand Rapids**, are of the usual type. The Warren is horizontal, in sizes from 3½ to 62 B.H.P. with single cylinder, from 20 to 125 B.H.P. with two cylinders, and up to 1,000 H.P. with four cylinders. The Grand Rapids is constructed with one, two, and three cylinders, from 1 to 45 H.P., and is used with adjustable propeller for boats and other marine work.

The **Otto** gas engine is made in America by the Company of that name at Philadelphia. About 8,000 engines are said to have been built from 1883 to 1900, the output now being about 800 per year. It is made vertical from 1 to 3½ B.H.P., horizontal from 1 to 120 B.H.P., for driving dynamos from 3½ to 36 B.H.P. When worked with gasoline no carburator is used. The oil is pumped from an underground air-tight tank to a valve acted on by the governor, which admits a given quantity to the cylinder, where it is immediately pulverised by a current of air,

and rendered inflammable. No air reaches the gasoline in its passage from the tank to the engine. The charge is fired by electricity, this being considered the safest method of igniting so explosive a mixture. The surplus oil is returned to the tank. Since the beginning of this century the Otto engine has been successfully applied to drive submarine torpedo boats. The engine is of the usual four-cycle type, with four vertical inverted cylinders. Each piston works downwards through long guides and a separate crank on to the crank shaft. The valves above the cylinders are worked by one horizontal cam shaft, driven from the

Fig. 142.—Otto Gasoline Engine for "Holland" Submarine Torpedo Vessel.

main shaft through a vertical intermediate shaft; the arrangement is clearly shown in Fig. 142. The cylinder heads and valve chambers are water-jacketed. The cranks are set at an angle of 180°, thus giving an impulse per revolution, and the charge is fired electrically in one or other cylinder, at each down-stroke of the motor piston. The "hit-and-miss" centrifugal governor acts on the oil supply, and cuts it off from one or more cylinders, according to the load. With several cylinders this method of governing gives satisfactory results. A characteristic of the Otto gasoline type is that the cylinders are in pairs, each set of two

having a common water jacket. The engine is started by compressing a charge of oil and air into each cylinder by hand. As soon as the supply is sufficient, the electric current is switched on, an explosion obtained in one cylinder, and the engine begins to work. The first engine fitted to a torpedo boat developed on trial 190 B.H.P. at a speed of 160 revolutions per minute, and a consumption per B.H.P. hour of 0·88 pint of light oil of 0·74 specific gravity. Engines of this type for seven submarine torpedo boats of the United States Navy have now been built, or are in hand. For a full account see *Journal of the American Society of Naval Engineers*, vol. xiii., No. 1.

The **Lawson** engine, for gas or kerosene, of the usual type, is made vertical only in sizes from ½ to 15 B.H.P. single cylinder, and 20 to 30 B.H.P. with two cylinders. All the valves are positively worked from a valve shaft running horizontally across the engine below the cylinder. The exhaust, air inlet, and gas admission valves are driven by cams and rods from this shaft. The air valve is opened before the gas valve, and the pure air first entering across the cylinder head is said to cleanse the cylinder of the products of combustion. Ignition is by hot tube without a timing valve, the governor acts upon the gas, and regulates the supply according to the demand.

The **Racine** is a small horizontal four-cycle engine for gas or gasoline, made from 2 to 4 B.H.P. Ignition is by hot tube or electricity. The exhaust valve is driven by a cam and rod from the reducing gear, and the governor acts on a controlling disc, and slips it on to or off the exhaust cam as required. The oil pump is driven from a small side shaft in the usual way. A little air is drawn through a jacket surrounding the exhaust gases, and conveyed to the mixing chamber, where it meets and volatilises the gasoline. More air is then drawn in near the admission valve, to render the charge inflammable.

The **Climax** is a four-cycle gas engine, made horizontal, in sizes from 1½ to 100 B.H.P., and having the exhaust and admission valves driven from a cam shaft geared to the crank shaft. The governor on the same shaft acts upon the gas valve, and closes it wholly or partially, according to the speed. Ignition is by hot tube. The end of the cylinder farthest from the crank is spherical, and has a water jacket.

The **Wing** is a four-cycle gas or gasoline engine, made with one or two cylinders, and chiefly intended for marine work or road carriages. Admission and exhaust are by cams on a valve shaft. The oil is injected through a nozzle into the vaporiser, the valve being worked by the admission rod. Ignition is electric. The engine is made in sizes from 2 to 6 H.P. single, and 4 to 12 H.P. double cylinder. A 2½ B.H.P. engine, running at 500 revolutions per minute, will drive a small boat at a speed of 8 or 9 miles an hour.

The patents of several important English and foreign engines have been acquired by American firms; mention of them will be found under the heads of the different motors. Among these the Koerting engine seems much in favour, and the American licencees, the De La Vergne Refrigerating Machine Co., are said to be the largest gas engine makers in the world. The Snow Steam Pump Works, Buffalo, are also among the builders of the largest engines. Drawings and a description of a 4,000 H.P. gas engine plant constructed by them, will be found in Mr. H. A. Humphrey's paper, "Recent Progress in Large Gas Engines," pp. 18, 22.

CHAPTER XXII.

FRENCH AND SWISS OIL ENGINES.

CONTENTS.—Light Oils in French Engines—Lenoir—Simplex—Sécurité—Tenting—Durand — Forest — Niel — Merlin — Quentin — Robuste — Brouhot — Roger—"Gnome" — Delahaye — Duplex — Swiss Oil Engines — Martini — Bossard—Schweizerische Maschinen-Fabrik—Schmid—Escher, Wyss & Cie.

FOREIGN oil engines may be divided into motors driven by ordinary heavy petroleum, of 0·80 specific gravity and upwards, and those using volatile oil spirit or benzine, of 0·65 to 0·71 specific gravity, or alcohol. Such a classification hardly exists in England, where the use of the lighter oils is almost exclusively confined to motor cars (which are not treated of in this book), and small marine engines. Benzine of 0·71 specific gravity consists roughly of 86 per cent. carbon and 14 per cent. hydrogen, and requires to burn it 3·41 times its weight of oxygen, or 14·83 times its weight of air at 68° F. Its approximate heating value is about 18,500 B.T.U. per lb. The storage of benzine is restricted by law in England; in Germany it pays no duty, while in France it is hardly more expensive than ordinary oil. On this point M. Durand remarks "that the use of heavy petroleum complicates the working of an engine by adding a vaporiser." Heavy oil cannot, he says, be completely evaporated, but must always leave an incombustible residuum, causing waste and clogging the parts. He thinks it "a mistake to attempt to distil the oil in the engine itself, when mineral essence, already distilled, can be obtained. By the use of heavy petroleum one of the principal advantages of internal combustion motors, that they can be started at once, is also lost, since from ten to twenty minutes are required to heat the vaporiser." Only a carburator of the simplest description is required with engines driven with benzine, alcohol, or "petrol," instead of a vaporiser, the heat of which must be always carefully regulated.

Oil engines are not much used in France, on account of the high price of ordinary heavy petroleum, but French engineers have been the pioneers in the construction of small engines driven with "petrol" or benzine, for road carriages. In this branch of engineering science they stand without a rival. Although most of these little motors, as the Daimler, Benz, &c., were originally of German invention, their adaptation for road locomotion is almost exclusively due to French ingenuity and skill. The oil engines described in this chapter do not therefore wholly represent

French progress during the past five or six years, since this is to be sought for rather in the small engines—marvels of complicated details—which are now turned out by thousands from so many French workshops.

Lenoir.—To this motor a carburator has been added, in which light oil of 0·65 specific gravity is used. A view is given at Fig. 143, the action being the same as in the Lenoir gas motor. The position of the carburator above the cylinder is near enough for the heat of the engine to keep the oil in a proper fluid condition, and counteract the cold of evaporation, but not near enough to convert the oil into vapour. Hence the use of lighter petroleum, which can be evaporated without much heat. The cylindrical carburator, at the top of the figure, is attached to

Fig. 143.—Lenoir Petroleum Engine.

the engine, and a very slow rotatory movement is transmitted to it, as shown, by a small strap and worm wheel, running at 4 revolutions per minute.

Lenoir at first divided the carburator or rotating cylinder into compartments filled with sponge or other porous substance. In the later type, a number of small semi-circular troughs are set round the inner circumference of the cylinder. The bottom is half filled with gasoline, and as the cylinder rotates, the troughs pass successively through the oil, and are filled. Raised by the continued movement of the carburator, each in turn is emptied of its contents, which fall in a fine rain back into the oil below. The carburetted air is then conveyed to the motor

cylinder through a passage or bulb, in which metallic wires are fixed, to prevent the flame from shooting back into the carburator.

A series of experiments were made by M. Tresca on a 2 H.P. and a 4 H.P. engine working with carburetted air; the density of the oil used was 0·65. The motor is made by Rouart Frères, single cylinder, in sizes from 1 H.P. upwards, and for portable motors and boats, with two cylinders, one above the other. Fig. 144 shows an indicator diagram.

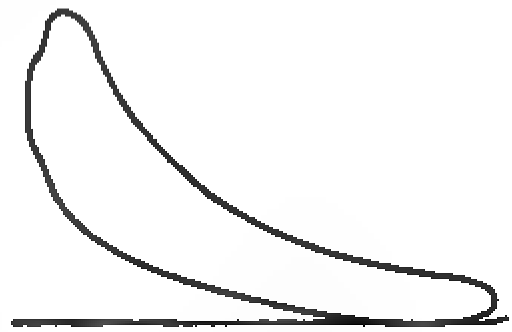

Fig. 144.—Lenoir Petroleum Engine—Indicator Diagram.

Simplex.—The original Simplex gas engine of MM. Delamare-Deboutteville and Malandin, described at p. 129, was supplemented by a carburator shown at Fig. 145. Here R is the tank, usually open at the top to the atmosphere, D the valve for admitting it into column E; B is a spiral horse-hair brush, which breaks the oil falling on to it into spray; at C is the casing round the column, heated by the hot water from the motor cylinder jacket. This water leaves the jacket at a temperature of 60° to 70° C. and falls to 40° or 50° C. by the time it reaches the carburator, where it helps to counteract the cold produced by evaporation. F is the small cock from which water falls, mingles with the narrow stream of oil entering through D from R, and the two filter through the spiral brush into the vessel L below, to which they are admitted through the valve V. The suction stroke of the piston draws air from the top of the carburator through the column C, where it is charged with petroleum vapour, and carried off from the vessel L through the pipe S to the motor cylinder. A safety valve hinders the flame produced by the explosion of the charge from shooting back into the carburator. The hot water prevents clogging of the valves by the oil deposit.

Fig. 145.—Simplex Carburator.

An engine called the "English Simplex" has been brought out by G. Davies of Abergavenny, but does not seem to have come to the front.

It is of the ordinary four-cycle type, with a vaporiser, and bears no resemblance to the original Simplex in its working method.

Sécurité.—A horizontal petroleum engine patented by MM. Diederichs, and known as the "Sécurité," appeared at the Paris Exhibition of 1889. It was rather complicated, but self-contained, requiring no external connections of any kind. The oil used was preferably heavy mineral oil, distilled from bituminous schist, of 0·82 to 0·85 specific gravity; a lighter petroleum spirit was required to start the engine, and for the ignition. The auxiliary shaft driven in the ordinary way from the crank shaft worked the ignition, admission, and exhaust valves by two cams and crank levers. The admission of oil to the vaporiser, a coil of pipes heated by the exhaust gases, was regulated by the governor, and the vaporised oil at high pressure issued out through a nozzle, carrying with it a current of air. The light oil for the lamp was forced drop by drop by an air pump into another current of compressed air, and further heated by passing through a second small coil of pipes. The burner consisted of a small platinum capsule maintained at a red heat by the flame. This engine is now made vertical, with a vaporiser of the Daimler type, for motor cars.

To the original **Tenting** engine a carburator of the simplest description has been added. It is a cylindrical vertical reservoir in three parts, the volatile hydrocarbons are stored in the upper, and thence pass to the second chamber. The products of combustion from the cylinder are led through the lowest division, warm the carburator, and counteract the cold produced by the evaporation of the hydrocarbon liquid. The Tenting carburator is a good example of the method of carburetting air by bringing it in contact with light hydrocarbon, without the application of much heat. The air, drawn in by the out-stroke of the piston, enters on one side, and is carried off from the other to the cylinder, charged with the volatile petroleum essence. This engine has been adapted for portable work, and for road carriages and boats; it is now used almost entirely for motor cars. The charge can be fired either by electricity or hot tube, and for so small a motor no water jacket is required, the cylinder being ribbed externally.

A similar engine was the **Durand** (1889), in which only the light volatile constituents of the oil were used, the heavier hydrocarbons being allowed to accumulate at the bottom of the carburator, withdrawn and wasted. The carburator was fixed above the cylinder, the heat from which counteracted the cold produced by evaporation. Air was drawn through it automatically by the suction of the piston, and as the level of oil was kept constant by a weighted float, the air always passed through the same quantity, and the quality of the charge admitted to the cylinder did not vary. This little engine appears to be no longer made.

Forest.—M. Forest, of Paris, in conjunction with M. Gallice, has produced several marine engines working with petroleum, which attracted the attention of the French Government. He claims to be the first to work an oil engine with four cylinders. A 30 H.P. engine with six cylinders, bought by the French Admiralty, was tested at Brest in 1890. In this engine a carburator on the Piéplu system is used, with light oil of 0·70 density. The surface of the petroleum is agitated by a rotating cylindrical brush. The air is drawn in by suction, and the petroleum being sprayed into it by the brush, it becomes charged with the evaporated liquid. These marine Forest motors are reversible, rapidly started, and the direction of the engine can be instantly changed. They have two or more vertical cylinders working downwards on the crank shaft. A distributing shaft, with a double set of cams driving the ignition and exhaust valves, runs above the cylinders, and by slightly shifting the position of the cams to the right or left, one or the other set can be brought into play. The charge is fired electrically. Drawings of this ingenious motor will be found in Witz. It is now made from 4 to 200 H.P. with four cylinders, chiefly for use in motor cars, and the consumption is said to be about 1 lb. oil per H.P. hour.

Niel.—With the exception of the vaporiser, all the chief parts of this petroleum motor are similar to those of the Niel gas engine. There are two valves, one above the other, for the admission of the charge to the cylinder, and discharge of the exhaust gases; both are driven by cams and levers from the auxiliary shaft. Ignition is by a tube without a timing valve. As it is the end of the ignition tube furthest from the cylinder which is kept red hot by the lamp, the charge only penetrates to this hottest portion at the moment of highest compression—that is, the outer dead point—and is fired in the usual way. The oil used is ordinary petroleum, of 0·80 density, and flows by gravity from a reservoir above, the level in which is kept constant by a float. From hence it passes partly to the vaporiser, partly to feed the lamp heating it and the porcelain ignition tube. The lamp, which is separate from the engine, consists of a small jet of oil vapour issuing from the orifice of a pipe, which is always kept alight, and maintains a horseshoe shaped tube over it at a red heat. Above is the vaporiser, a small cylindrical vessel with an outer jacket and internally ribbed surfaces; the oil drops into the vaporiser from a hopper, the quantity entering at a time being regulated by a cock; it is about one-tenth of a gramme per H.P. per stroke. Before starting, a little spirit is ignited in a shallow vessel below the lamp, and heats the tube and vaporiser, until sufficient vapour has been generated to make the lamp ignite spontaneously. The exhaustion of the spirit in the vessel should coincide with the attainment of a red heat by the tube and vaporiser. As soon as the lamp is started,

the hot gases from it circulate through the jacket of the vaporiser, and keep it at a high temperature. The lamp is protected by a shield.

Air enters through an automatic valve, and carries the oil with it into the vaporiser, where it is evaporated, and the two pass to the valve chamber and cylinder through an admission valve. The valve shaft is driven half speed from the crank shaft. The flexible three-armed governor is the same as in the Niel gas engine. It is worked by an eccentric from the valve shaft, and acts upon the lever opening the exhaust, which is connected to that working the oil admission valve. If the normal speed is exceeded, the exhaust is held open, and the same action suspends the flow of oil. Thus the admission is made to depend upon the opening of the exhaust valve.

A stationary and a portable Niel engine were shown at the Meaux trials, in which the consumption of oil at full power was 0·83 lb. and 1·6 lbs. per B.H.P. hour respectively. Horizontal engines are made in sizes from 3½ B.H.P. upwards, and run at 190 to 160 revolutions per minute. A small vertical type called the "Atlas," lately brought out, is made from 3 to 6 B.H.P., with a speed of 240 revolutions per minute, and portable engines, both horizontal and vertical, are also constructed. Several hundred engines have been sold, and there is a considerable demand for them in France, on account of their strength and durability.

Merlin (1894).—This oil engine is constructed by MM. Merlin et Cie., Vierzon, Cher, chiefly for agricultural purposes. Of the motors tested at Meaux it ranked among the best, both on account of the low consumption of oil, and of the high heat efficiency, as will be seen from the Table of Tests.

The engine somewhat resembles the Grob in its construction, and method of vaporising the oil. The vertical cylinder is above, the crank below, and between them is a valve shaft driven by wheels 2 to 1 from the crank shaft. The oil used is ordinary petroleum, and is contained in a receiver in the base, from whence it is drawn by a small pump, and sent drop by drop, as required, into the red-hot vaporiser. The latter is ribbed internally to afford a large heating surface, and kept hot by a lamp fed from a second small reservoir of oil, the pressure in which is maintained by an air pump. The oil may also be run to the lamp by gravity from a receiver above, and the air pump dispensed with. The exhaust valve and air and oil pumps are worked by cams and levers from the valve shaft. The oil injected into the vaporiser by the pump is pulverised by the air entering with it through a very small passage, and instantly evaporated by the heat. There is no timing valve, the vaporiser, which also acts as an ignition tube, being open to the cylinder. A larger current of air, admitted through an automatic valve lifted by the vacuum in the cylinder, enters from above, and mixes with

the oil vapour drawn in from the vaporiser by the suction stroke of the piston. The charge is compressed by the next in-stroke, driven into the red-hot vaporiser, and ignites spontaneously. The governor consists of a weight and spring carried on the flywheel. If the normal speed is exceeded, it throws the whole valve shaft out of gear, the exhaust is held open, no oil passes to the vaporiser, and no vacuum being produced in the cylinder, the automatic admission of air is suspended. In the engine shown at Meaux, the water sent to the cooling jackets was circulated by means of a pump. As the action of the latter was checked by the governor if the normal speed was exceeded, the cylinder did not, as in other engines, become unduly cooled, and the heat efficiency was consequently improved. The Merlin engine is made vertical stationary, single cylinder, in sizes from 1 to 13½ B.H.P., and runs at 450 to 270 revolutions per minute. The consumption at the Meaux trials was very low—viz., 0·78 lb. oil per B.H.P. hour, and the heat efficiency 16·2 per cent. Both the Niel and the Merlin discard the use of light, inflammable oil.

Quentin.—This engine made by MM. Quentin, at Valenciennes, for small powers, was intended principally for propelling road carriages, and is no longer used for other purposes. The same applies to the **Robuste,** built by M. Levasseur at Evreux, which is only employed for road locomotion. Both were from the first driven with light oil, vaporised in a carburator. In the vertical engine made by MM. **Millot** at Gray in Savoy, and now no longer constructed, heavy petroleum was used.

Brouhot.—The petroleum engine made by MM. Brouhot, of Vierzon, is similar to the gas engine described at p. 152, with the addition of an apparatus for evaporating the oil. This consists of a vaporiser, a large reservoir above it, and an intermediate receiver, to regulate the supply of oil. By means of the latter vessel the level of liquid in the vaporiser is maintained uniform, and the air always charged to the same extent with volatile petroleum. The oil is pumped to the top of the vaporiser, and falls in its descent through a perforated screw; the air as it passes upwards meets it, and becomes thoroughly carburetted. The vaporiser consists of a hollow circular chamber, round which the exhaust gases are led, to heat it. In the latest types a minute quantity of oil passes from the receiver into a small cavity, from whence a current of air sweeps it to the vaporiser, and the suction of the motor piston draws the charge of oil and air into the cylinder. Electric ignition is used, and in other respects the engine does not vary from the usual four-cycle type. It is sometimes driven with schist oil, which is similar to Scotch shale oil, or with alcohol. It is made vertical from 1 to 4 H.P., horizontal, with one cylinder 1 to 25 H.P., with two cylinders up to 30

H.P. As a portable engine it has already obtained considerable success. The consumption is said to be about 1 lb. of oil per H.P. hour.

Roger.—The small vertical oil engines formerly made by M. Roger were compact and very simple. The petroleum used was of 0·70 specific gravity, and was evaporated in a carburator placed at the side of the engine. Ignition was by a hot tube. These little motors were especially intended for manufacturing purposes and motor carriages, but the business has now been taken over by M. Serpollet, the well-known maker of steam carriages.

The "**Gnome**," made by Séguin, of Gennevilliers, to work with petroleum, is of the German type, and all the organs, including the crank and motor shaft, are enclosed. For a description of the working method see Chapter xxiii. on German oil engines. The French makers build the engine vertical only, in sizes from 1 to 22 B.H.P., with a speed of 400 to 250 revolutions per minute. It has been adapted for use in motor cars, with one, two, or four cylinders, in sizes from 6½ to 45 H.P., and runs at 1,500 to 750 revolutions per minute. It is also made portable, driven with alcohol or petroleum, for powers from 2 to 30 H.P.

A small vertical gas engine, which has been adapted for use with petroleum, is the **Delahaye**, made by Lacroix & Cie. at Tours. It is for small powers, and intended chiefly for agricultural and manufacturing purposes, and for road locomotion. It is also driven with alcohol, and a simple type of carburator is used. The alcohol is admitted into a small reservoir, the level in which is maintained constant by a float, and passes thence into a larger receiver carrying a central vertical tube. Air is drawn down by suction through the tube, passes up through the alcohol, with which it is thus impregnated, and the two are led through a perforated metal plate to the admission slide valve, where they are mixed with a further supply of pure air, to form the explosive charge. The position of the slide valve regulates the proportions of air and alcoholic vapour, and the amount of the charge passing to the cylinder is controlled by a throttle valve.

Duplex.—This engine, described at p. 153, is also worked with petroleum, alcohol, or light "petrol," and appears to have come much to the front, as an oil motor, of late years. Oil from a reservoir above the engine is injected, together with air to pulverise it, into the vaporiser, which is heated by a lamp, and also by the exhaust gases. It consists of two concentric chambers; the inner forms the vaporiser itself; through the outer, which is arranged as a jacket round it, the exhaust gases are circulated, before passing thence to a receiver and to the outer air. Ignition is by hot tube, heated by the same lamp as the vaporiser; the oil for the lamp is drawn from the reservoir

supplying the engine. The governor regulates the speed by holding the exhaust valve open, and throwing the admission valve out of gear. The gases of combustion are drawn back into the cylinder, and the vaporiser is not unduly chilled by cutting out explosions.

A special feature of this engine is its application in France to work fishing trawlers, in place of steam. On a large fishing boat, the *Jean*, at Boulogne there are two Duplex oil engines, each with two cylinders, one of 40 H.P. for working the capstan, and one of 200 H.P. to supplement the sailing power, and ensure a quick return to port after the fish is caught. The smaller engine is also used for hauling the nets. The engines are driven by heavy petroleum, pumped direct from oil trucks run on to the quay at Boulogne into tanks on board the vessel. The larger engine is started by compressed air, pumped at a pressure of 170 lbs. per square inch by the smaller engine into a receiver. The motor itself runs at a uniform speed of 300 revolutions per minute, it is its action upon the screw which is varied. If more power for propelling the boat is required, the two engines can be coupled. Oil engines are said to be greatly superior to steam on these small fishing boats, where the work is intermittent, and large demands are often suddenly made on the engines. They have been much used in Denmark, and more than 500 Danish boats, from 3 to 50 tons burden, are said to be now driven with oil. They are also employed in America for mackerel fishing. In this industry the advantages of oil engines in ease and rapidity in starting, and simplicity in working, greatly outweigh those of steam engines, only two men being required to work a boat of 136 tons burden. The *Jean* has a speed of 8 knots an hour, and the consumption of oil is said to be about 0·7 lb. per B.H.P. hour.

The Duplex engines for petroleum or alcohol are also made portable, in sizes from 1½ to 50 H.P. horizontal, with a speed of 280 to 180 revolutions per minute, vertical from 2 to 8 H.P., running at 400 to 300 revolutions; when worked with petroleum essence they develop from 1 to 7 H.P. About 180 motors have been made for France and Africa, chiefly for industrial and agricultural purposes.

Several smaller French oil engines, as the Crouan, Régent, Noël, Japy, &c., described in former editions, have now dropped out of notice, or are only made for motor car propulsion. Belgian makers of oil engines are J. Gilain at Tirlemont, and MM. **Longdoz** at Liége.

Swiss Oil Engines.—Not many oil motors are made in Switzerland, but a considerable impetus was given to their manufacture by the Geneva Exhibition of 1896. MM. **Martini**, of Frauenfeld, still make horizontal single-cylinder four-cycle engines, for use either with petroleum essence or ordinary oil. This firm exhibited a 30 H.P. and

a 2 H.P. oil motor at Geneva, but of late years they have not constructed many.

A small four-cycle oil engine with electric ignition is made by **Bossard**, of Geneva, two types of which were shown at the Exhibition of 1896. The oil and admission valves are automatic, and the exhaust is opened by an eccentric on the crank shaft. By an arrangement of rods and levers a tappet on the rod of the eccentric misses the valve at every other revolution, and the exhaust remains closed. The speed is regulated by a centrifugal governor, driven from the crank shaft, which holds the exhaust valve open till the speed has fallen. The vaporiser is placed between the oil and admission valves. The spindle of the little oil valve carries a disc, over which the oil falls in a thin veil, and the current of air pulverises it, and forces up the valve with great regularity. The ignition tube and vaporiser are heated by an external lamp, and there is no timing valve. The engine is made horizontal and vertical, in sizes from 1 to 18 H.P., with a speed of 350 to 190 revolutions per minute; about seventy are in use, chiefly in Switzerland. These little motors are worked with benzine or light petroleum; a few have been driven with lighting gas.

Two small oil engines made by **Henriod Schweizer** and **Bächtold** were shown at Geneva in 1896, but do not seem to have maintained their place in the market. In the former the red-hot compression space at the end of the cylinder, forming the vaporiser, was ribbed to retain the heat. The oil entered a small space above the valve, the size of which could be varied according to the quantity of oil required. As the valve was drawn down by the vacuum in the cylinder, the oil in falling was thinly spread out over the conical seat of the valve, pulverised by the current of air, and carried on to the compression space. In the Bächtold the method of vaporising the oil was the same. The exhaust valve remained open during part of the admission stroke, and some of the products were drawn back into the cylinder, together with a small quantity of air, through an automatic valve in the exhaust passage. By this means a rich mixture was said to be always round the admission and hot tube, and a poor mixture close to the exhaust.

The **Schweizerische Maschinen-Fabrik**, Winterthur, make a well-designed and carefully-constructed engine to work with ordinary petroleum of 0·79 to 0·83 specific gravity, several types of which were exhibited at Geneva. In the portable motor there is no oil pump. The petroleum runs by gravity from a receiver above, part going to the lamp, and part being carried on in a liquid state to the vaporiser by the inrush of air; the quantity admitted per stroke is about $\frac{1}{12}$ gramme per H.P. There are two cams on the valve shaft for admission and exhaust, the

admission is connected by levers to the oil valve, and both work together. The governor acts upon the exhaust, and holds the valve open to reduce the speed, and at the same time checks the admission valve. In the horizontal type the oil and admission valves on the opposite side of the cylinder to the valve shaft are worked by the same cam and lever. The rotary ball governor acts upon a graduated cam, and varies the richness of the charge in inverse ratio to the speed. About 9 gallons of cooling water per H.P. hour are required; the water can be used continuously, and is cooled in a ribbed refrigerator. These engines may be worked with either benzine or ordinary petroleum; in the former case ignition is by electricity, with a hot tube in reserve. They are built vertical from 2½ to 7 H.P., horizontal from 2 to 40 H.P., and run at a speed of 250 to 170 revolutions per minute. In the smaller sizes there is no timing valve. This noted firm make a large number of oil engines every year, several of which the author saw at work. They run well, are carefully built and fitted, and are especially useful as a reserve, to supplement water power, which is much used in Switzerland.

In the little vertical oil engine, made by **Schmidt**, of Zurich, the oil and air are vaporised in the usual way, but special care is taken to prevent unvaporised oil from passing to the cylinder. It flows by gravity from a receiver above, and is sent on by a little pump with adjustable screw; a throttle valve regulates the admission of air. The double lever working both valve and pump is under the control of the governor, which checks the speed by not opening the valve. The hot tube without a timing valve is heated by a lamp.

MM. Escher, Wyss & Co., of Zurich and Ravensburg, are also makers of engines driven with ordinary petroleum. By the suction of the piston the oil in these motors is drawn under pressure from a reservoir in the base, through an automatic valve and a nozzle, into the vaporiser, together with a current of air from a vessel surrounding the exhaust. It then passes to the ignition channel, where it is mixed with more air admitted through a valve, driven, like the exhaust and ignition valves, by cams from a side shaft, at half the speed of the crank shaft. At the end of the compression stroke the charge is fired by a hot tube. The ball governor, placed above the side shaft, holds the exhaust valve open and the admission closed, if the normal speed be exceeded. The vaporiser and ignition tube are both heated by the same lamp. The engine is made from 4 to 60 H.P., and runs at 360 to 190 revolutions per minute. In a small vertical type, the "Meteor," the vaporiser is at the side of the cylinder, and the piston works downwards on to the enclosed crank. This little engine is made in sizes from 1 to 12 H.P., with a speed of 370 to 330 revolutions per minute.

CHAPTER XXIII.

GERMAN OIL ENGINES.

CONTENTS. — Daimler—Adam—Altmann (Marienfeld)—Koerting—Langensiepen—Kappel—Bielefelder Maschinen-Fabrik—Gnome (Oberursel)—Deutz-Otto—Alcohol Engines—Trials—Benz—Capitaine—Swiderski (Capitaine)—Bánki—Trials—Diesel—Latest Types—Trials—Kjelsberg—Nobel—Bechstein—Dresdener Gas Motoren-Fabrik—Lützky—Buda-Pesth Maschinen-Fabrik—Dopp—Russian Engines—Pétréano Vaporiser.

GERMAN oil engines have a wider range in the quality and density of their working agent than English motors, and are perhaps applied in

Fig 146.—Herr Daimler.

more directions. The advantages of using light oils are realised by most makers, especially by the builders of small engines, and alcohol is also very generally employed. As it is a native agricultural product in France and Germany, it is both cheap and easily procured everywhere, conditions which of course do not obtain in England. Both alcohol and benzine have the further advantage that they will bear higher compression than ordinary petroleum, without the danger of pre-ignition. Hence

engines thus driven have been carefully studied from a theoretical and practical point of view by several eminent German scientists, notably Professor Meyer. For his tests on portable alcohol engines, see p. 492.

Daimler.—This important little motor differs in some respects from the gas engine of the same name, described in the gas engine section. It has two single-acting cylinders, set vertically or at a slight angle, and working upon the same crank shaft, but the pistons have no valves. The sides and covers of the cylinders are cooled by water jackets; but these are often dispensed with, and the cylinder ribbed externally. Fig. 147 shows the arrangement of the parts, Fig. 148 the method of vaporising the oil. The air, previously warmed by the exhaust gases from the engine, is introduced in the direction of the arrows into the cylindrical upper part of the receiver A, Fig. 148. This is divided into an outer and inner portion by concentric wire gauzes, and through the centre passes the hollow spindle of a needle valve, conveying oil from the reservoir R into the lower part of A; the oil is kept at a constant level by a float B. Upon the top of this float, in the latest arrangements, rest the weighted ends of two small levers, the other ends of which, worked by two fulcra, grip a collar on the valve spindle. If the level of oil in the receiver sinks, the float falls, drawing down with it the weighted ends of the levers; the other ends being forced up lift the valve spindle, and more oil is admitted from below to adjust the level.

Fig. 147.—Daimler Oil Engine. 1890.

The hot air is drawn by the suction of the piston through the outer jacket of the upper cylindrical portion of A, and forced out at the bottom through the oil at L, its direction being regulated by the float. Thus it always passes through a layer of uniform thickness. The oil with which it is charged impinges against the plates H and F, and is broken up; part falls back into the reservoir below, and part is carried up with the current of air. The force of the air blast produced by the vacuum in the cylinder being always the same, and the level of oil con-

stant, the latter is said to be completely vaporised. The mixture then passes through the wire gauze to the admission valve H, where more air

Fig. 148.—Daimler Oil Engine. Vaporiser.

is drawn in—sufficient to make the charge inflammable—and thence to the motor cylinder; the arrows indicate the direction. The two valves

for admission and exhaust are placed one above the other in the same valve chest, and the lamp between them; thus the incoming charge is still further heated, before it passes to the cylinder through an automatic lift valve, as in the gas motor. The back stroke of the piston compresses the charge in the usual way.

Ignition is effected by means of two small external lamps (L, Fig. 147), one for each cylinder. These lamps are fed from the reservoir R, the valve cock p, and the receiver B; the supply of oil is regulated by the valve V, and the lamps burn with a clear blue flame. Within them are small nickel, platinum, or cast-iron rods, kept at a white heat, which fire the charge in either cylinder automatically, without a timing valve, at the end of the compression stroke. Upon the proper burning of the two lamps the efficient working of the engine in a great measure depends. The Daimler claims to be one of the first motors, if not the earliest, in which automatic ignition was introduced. The arrangement was necessitated by the high speed at which it runs, a speed so great that no valve gear could be relied on to give punctual ignition. Care is needed in the Daimler, Capitaine, and other engines to prevent premature ignition, since the red-hot vaporiser is always open to the cylinder. Special attention is always paid to the double admission of air, and the quantities are carefully regulated.

The exhaust valve is worked from the crank shaft by an eccentric. The governor on the flywheel regulates the speed by keeping the exhaust open if the normal number of revolutions is exceeded, and, admission being automatic, no charge can enter. The engine is started by means of a hand crank, which carries a wheel gearing into another on the motor shaft. As soon as the engine is at work, its speed being greater than can be overtaken by the hand crank, the latter slips out of gear.

The Daimler motor works with petroleum of 0·68 specific gravity and upwards, and is much used for road carriages, boats, fire engines, pumps, &c., on account of its small dimensions and low consumption of oil. It may indeed be said to form the typical engine for motor car work. The original type with two cylinders set at an angle is used chiefly for portable and boat engines, the later type with vertical cylinders for stationary motors. Except for road locomotion, the latest engines have only one cylinder. They are made vertical only, in sizes from ½ to 10 H.P., stationary, and run at 540 to 250 revolutions per minute, with one or two cylinders. For boats they are constructed with one, two, or four cylinders, with a maximum speed of 580 revolutions, and in sizes up to 25 H.P. The latest engines run at 750 revolutions per minute (see Chapter on Practical Applications). For tests, see Table at end of book.

Adam.—The Adam petroleum engine resembled the gas motor of the

same name, with the addition of a vaporiser, but is now no longer made. It was one of the earlier engines to use benzine as the motive agent.

Altmann (Marienfeld).—This engine, formerly made by Altmann, of Berlin, and now by the Marienfeld Motoren-Fabrik, is compact, simple, and has met with considerable success as a stationary or portable agricultural motor. It is now principally worked with light petroleum or alcohol. In the original vertical type the piston worked upwards on to the crank. Admission, ignition, and exhaust were effected from a horizontal auxiliary shaft, worked from the main shaft by two sets of conical wheels. The petroleum was delivered by a small pump with adjustable stroke to the vaporiser, a shallow vessel heated by a spirit lamp, into the flame of which the hot ignition tube projected. The vaporised oil then passed to another valve chamber, where it was diluted with air before entering the cylinder. The oil pump and the suction valve admitting the oil from the reservoir were worked from the same lever, by a roller and cam on the auxiliary shaft. If the engine ran too fast, the cam was thrown out of gear by the ball governor, and missed the roller, and no oil entered the cylinder until the speed was reduced. The later types of this engine are made horizontal.

The admission is immediately above the exhaust valve, and both are worked by cams and levers from the auxiliary shaft, from which the little oil pump is also driven. The oil flows by gravity from a receiver above, falls over the cone of the valve in a thin stream, and is pulverised and carried on into the admission valve by a current of air entering at the side. This air is heated by the exhaust gases, and the proportions can be varied by a throttle valve. An "oil pocket" below receives any unevaporated oil. On reaching the admission valve chamber the direction of the oil vapour and air is suddenly changed, and as the chamber is not cooled, the heat of the explosions and of the exhaust gases is sufficient to convert the oil and air into an explosive charge. The ignition tube is open to the cylinder without a timing valve, and is heated by a flame fed by oil from a receiver. The governor acts on the oil and admission valves, regulates the time of opening, and prevents the cam on the valve shaft from reaching the rod, if the speed is too great, the exhaust meanwhile working as usual. A novelty in the portable engine exhibited at the Berlin oil motor trials was that the compression space could be reduced in size at starting, and expanded to its full dimensions as the engine became hot. At these trials this was the most economical of all the portable engines, and was highly commended, the consumption being only 0·83 lb. of oil per B.H.P. hour. In a 25 H.P. double cylinder portable engine, shown at the Berlin Exhibition of 1896, the water to cool the cylinder was not circulated as usual, but was fed into the jacket, where it remained till it had wholly evaporated through a blow-off cock and pipe.

In this class of engine this arrangement has its advantages, and is said to produce a considerable economy of water (see Table 9, Nos. 29 and 34 for tests).

The engine is also made to work with alcohol, and was shown at the Berlin trials, in 1902 (see p. 492), where it obtained a first prize. The same care in design is shown in this as in the earlier motors, and special attention is paid to the speed, and the temperature of the air for spraying the spirit. The alcohol is admitted from a receiver above through a small valve connected to the admission valve, and injected at right angles into the air passage. The stroke of the vapour valve is regulated by an adjustable screw. The air is drawn in through a pipe surrounded by the hot exhaust gases, while a throttle valve in the pipe determines the quantity admitted per stroke, and thus varies the proportions of alcohol and air. At full load this arrangement causes the engine to become too hot, a valve can then be opened to admit a second supply of cold air into the admission passage. Ignition is by electricity, and the time of ignition can be varied, and made to precede the dead point, to prevent the engine starting backward. The governor acts on the "hit-and-miss" principle on the exhaust valve, and holds it open if the normal speed is exceeded, thus checking the rise both of the admission and of the oil valve. Like all alcohol engines, the Marienfeld is started with benzine.

Koerting.—In this engine (see Fig. 149), when driven by ordinary petroleum, the oil flows by gravity from a receiver above, the air is drawn in at the side by the suction of the motor piston. Both are admitted through one automatic valve, and the oil is then sprayed or pulverised by drawing it down into the vaporiser between two discs, at the same time as the air current. The three processes of admitting the oil and air, and pulverising the former, take place simultaneously, and are in proportion to the pressure in the cylinder. The dimensions of the oil valve are so adjusted, that the opening uncovered when the rod is lifted is always less than the aperture, and thus the composition of the charge is maintained uniform. The oil and air then pass to the vaporiser, which is kept at a red heat by the flame heating the ignition

Fig. 149.—Koerting Oil Engine.

tube, the oil is evaporated, and the mixture admitted to the cylinder. If benzine is used as the motive power, it is introduced together with the air through one automatic double-seated valve, and there is no vaporiser, properly so-called. The oil passes down through the hollow valve-rod, the quantity being regulated by a small pin, and spreads out over the conical seat of the valve. The air, drawn in at right angles, breaks up the thin veil of petroleum, and the mixture passes to the cylinder through a non-return valve, as in the gas engine. The ignition tube has no timing valve, and is only red hot at its further end. When the compressed mixture in the cylinder comes in contact with this red-hot part it ignites, and a perfect explosion is said to be obtained. Both the vaporiser and ignition tube are heated by a lamp, so arranged that the pipe conveying the oil to it is carried through the flame. The exhaust is the only valve driven by gearing. The speed is regulated by a momentum governor acting on a knife edge. If the normal speed is exceeded, the governor interposes the knife below the lever opening the exhaust, and keeps it open. Since no compression can take place no charge is admitted; there is no suction stroke, and the automatic admission valve does not rise.

A small vertical two-cycle type has lately been introduced for driving motor cars and for marine work. It has no valves, the piston itself closes and uncovers ports in the cylinder for admission and exhaust. The charge is fired by electricity. The working method, especially the compression of air into the crank shaft below by the down stroke of the piston, somewhat resembles that of the Day. A peculiarity of this little Koerting engine is that the number of revolutions can, it is said, be varied from 250 to 1,000.

In engines driven by alcohol the spirit flows by gravity from a small receiver above to the vaporiser, a chamber enclosing the double-seated automatic mixing valve, and heated by the exhaust gases, which are carried round it. In some types the temperature of the charge is further raised by the hot gases from the lamp heating the ignition tube. The quantity of alcohol passing to the valve is regulated by a screw. The air, to which a spiral motion is imparted by the shape of the valve, is admitted through the outer, and the alcohol at right angles to it through the inner seat, and both pass to the admission valve, the vacuum in the cylinder determining the proportions. Governing is on the "hit-and-miss" principle. This engine was shown at the Berlin trials of portable alcohol engines in 1902.

Large Koerting engines are governed by varying the quality of the charge. For petroleum, benzine, or alcohol, the engine is made from 2 to 35 H.P., and runs at 320 to 160 revolutions per minute. Several

motors to work with benzine have been supplied to Baku in the Caspian oil district. For a test see Table 9, No. 69.

Langensiepen.—A petroleum engine constructed by Langensiepen, of Magdeburg, and designed by Herr v. Lüde, has been tested by Professor Schöttler. It is a horizontal four-cycle motor, self contained, with hot-tube ignition. The admission, distribution, and exhaust valves and oil pump are worked by cams and levers from the auxiliary shaft, driven from the crank shaft by spur wheels. The ball governor upon the crank shaft, inside the driving pulley, acts by cutting out the number of explosions. The oil falls by gravity from a petroleum tank above the cylinder, and passes through the suction valve of the oil pump. The stroke of the pump is always the same, but only a certain quantity of oil is injected into the hot admission passage, while a variable portion is returned to the reservoir. The oil is sprayed into the air, broken up by striking against the seat of the valve, and the two pass to the vaporiser, a bent tube of large diameter, open on one side to the cylinder, on the other to the ignition tube without a timing valve. At starting, the ignition tube and vaporiser are heated by a lamp, but as soon as the engine is at work, the lamp is drawn back, and only heats a certain part of the ignition tube. In the 6·7 I.H.P. motor, tested by Professor Schöttler, the consumption of oil was 1·1 lbs. per B.H.P. hour (see Test No. 60, Table 9). In the portable engines exhibited at the earlier Berlin trials the pressure of the exhaust gases was utilised to draw a current of fresh air through the cooling water tank. The engine is fully illustrated in *Zeitschrift des Vereines deutscher Ingénieurs*, August 29, 1891, and June 12, 1897, but its manufacture has now been superseded.

At the present time (1905), the Langensiepen firm make engines of the usual four-cycle type, to work with ordinary petroleum, benzine, naphtha, or alcohol. They are of very simple construction, only the exhaust valve being driven by gearing; the air and oil valves are automatic. The centrifugal governor acts on the hit-and-miss system on the admission valve, and holds it open, if the normal speed is exceeded. There is no oil pump, but the air drawn in regulates the admission of oil, and ensures that only the proper quantity per stroke shall be sent on to the vaporiser. Thus the danger of premature ignition is avoided, as the small amount of oil which reaches the cylinder is instantly ignited. The consumption is said to be from 0·7 to 0·9 lb. of ordinary petroleum per B.H.P. hour. Ignition is by hot tube, but in engines driven with benzine and alcohol the charge is fired electrically. Langensiepen engines to work with petroleum are made vertical, in sizes of 1 and 1½ H.P.; above this power, for the various kinds of oil and spirit, horizontal

only from 2 to 35 H.P., with a speed of 300 to 200 revolutions per minute.

The **Berliner Maschinen-Bau Gesellschaft** (Schwartzkopf) were one of the earliest firms to bring out a petroleum engine on Kaselowsky's patent, a description of which will be found in the Third Edition. It is now no longer made.

Kappel.—This firm makes engines to work either with petroleum or light benzine, and exhibited an oil motor at Antwerp in 1894. The oil in this engine is conveyed from a receiver by means of a small air pump, which raises the pressure in the receiver, and forces the oil to the admission valve, and to feed the lamp heating the vaporiser and ignition tube. The two latter are enclosed in a chamber at the back of the cylinder. The exhaust and air valves and petroleum admission valve are all worked by cams from the valve shaft. Air is drawn by the suction of the piston through a chamber filled with benzine, with which it becomes charged in the shape of vapour. The ball governor acts upon the cam opening the admission valve, and shifts it according to the load. If the engine is intended for electric lighting a stepped cam is used, that the charge may be rich enough to ignite at any load. Electric ignition is employed in the benzine engines, because of its greater safety. In the motor shown at Antwerp the oil pump carried two small pistons driven to and fro in a slide from a small crank on the valve shaft. One piston moved with the slide, the other acted only during part of the stroke. By an ingenious arrangement the pistons drew the oil into the little pump cylinder, and pressed it out between them into the pipe leading to the vaporiser. The governor acted by interposing a bar between these pistons if the normal speed was exceeded. The Kappel engines are made to work with ordinary oil or benzine, vertical from 1 to 3 H.P., and a speed of 350 revolutions per minute; horizontal from 1 to 25 H.P., making 220 to 180 revolutions per minute.

The **Bielefelder Maschinen-Fabrik** (Dürkopp) have shown oil engines at several exhibitions. At Berlin in 1894 the consumption was 1 lb. per B.H.P. hour (Test No. 46, Table 9); in the portable engine the water in the jacket was circulated by a small centrifugal pump. The benzine is contained under pressure in a receiver below the horizontal cylinder, and supplies the engine, the lamp for the hot tube, and the burner to heat the vaporiser at starting. The pressure is maintained by a small air pump driven from the engine, as in the Priestman. The oil for the charge passes cold through a sprayer into the red-hot vaporiser, where it is evaporated, the air being carefully excluded. It is then mixed with air, and conveyed to the cylinder, the quantity passing to the vaporiser being regulated by a ball governor. The vaporiser is above the exhaust valve, and is kept hot after the engine is started by the gases of

combustion, which are also carried downwards before they leave the engine, to heat the incoming air. The makers lay stress upon the fact that the light oil is sprayed while cold, no air being allowed to reach it during the process. The engine requires no lubricant except at starting, in all other respects it is similar to the Dürkopp gas engine.

Seck (Gnome).—This vertical oil engine, made by the Motoren-Fabrik, Oberursel, and exhibited at Berlin, where it was commended for economy, resembles the Capitaine in several respects, and especially in the method of vaporising the oil. The crank and motor shaft are below, and, with the valve gear, are enclosed in a chamber partly filled with lubricating oil, into which the connecting-rod dips at each stroke, and scatters it over the working parts. The cylinder is above, the piston acts downwards, and the air enters from the top and at the side, in both cases through automatic valves. The exhaust is driven from the crank shaft by an eccentric, on the circumference of which is a worm wheel gearing into another of twice the diameter; the latter carries a pin, which allows the exhaust valve to open only at every other revolution. There is no cam shaft. The centrifugal governor, also on the crank shaft, drives a pulley which, if the normal speed be exceeded, causes a pawl to catch in the spindle of the exhaust valve, and holds it open until the speed is reduced. A pump worked from the engine sends the oil under pressure from a separate receiver into a small vessel above the cylinder. From thence it is drawn through an injector by the suction stroke of the piston, together with a current of air through an automatic valve, into the vaporiser at the side. The air and oil vapour then pass to the compression space of the cylinder, where the charge is mixed with more air through another automatic valve. The compression stroke drives it back into the red-hot ribbed vaporiser, and causes it to ignite, as in the Hornsby, Capitaine, and other engines. A lamp is used to heat the vaporiser and hot tube, and the moment of ignition is determined by shifting the lamp, and causing it to play on any part of the tube. Electric ignition is now, however, more general. Special care is taken in this and similar motors that the quantity of air first admitted is insufficient for combustion, otherwise, the vaporiser being open to the cylinder, premature ignition might occur.

This motor has now been especially adapted for use with alcohol, and is said to have been one of the first portable engines thus worked. It was one of those taking part in the trials of portable engines at Berlin by Professor Meyer in 1902. The working conditions of the motor are practically the same when worked with alcohol as with oil, except the method of vaporising the alcohol. It is drawn from a receiver, the connection with which is always open, to the admission passage and inlet valve, by the suction of the piston. The little receiver is supplied from

a larger reservoir by a small pump, the quantity delivered being more than is required per stroke; the surplus is carried back to the reservoir through an overflow pipe. The admission passage is surrounded by the hot exhaust gases, which are also sometimes utilised to heat the incoming air. The passage acts as a vaporiser, and the spirit is injected into it through a nozzle, the quantity of alcohol, and thus its ratio to the air admitted, being regulated by a screw. The charge is always ignited by electricity, and there is no external flame. The makers of the Oberursel claim for it a leading position in Germany for driving portable engines, light locomotives, ploughs, &c., and for various domestic and agricultural operations, such as churning, sawing, threshing, &c. For these purposes it is very widely used, and about 3,000 are said to be at work. It is made vertical for use with ordinary petroleum from 1½ to 24 H.P., and runs at 400 to 250 revolutions; for alcohol or benzine, vertical from 1 to 25 H.P., above that size horizontal only. As a portable engine it is built in eleven sizes, from 2 to 20 H.P. It is also used for hauling in mines, to replace horse traction, and on light railways.

Deutz-Otto (1890-1905).—The German firm at Deutz make three types of engines to work with ordinary petroleum, benzine of 0·70 specific gravity, and alcohol. The price of the latter spirit has been reduced in Germany since 1900; hence it is extensively employed for small power engines. A drawing of the carburator used in most of the oil engines is shown at Fig. 150.

Fig. 150.—Benzine Carburator—Otto Engine.

The benzine is introduced through a filter into the receiver, which is heated by a hot-water jacket; in cold weather the exhaust gases are also carried through the bottom of the receiver, to warm it. The level of oil is maintained constant by the float. Air sucked in by the out-stroke of the piston enters the receiver as shown, and is drawn up from the bottom of the liquid through a nozzle, to divide and saturate it as much as possible. From hence the carburetted vapour is conveyed to the cylinder through a vessel filled with pebbles to cleanse it; return and

safety valves and a wire sieve prevent the flame from striking back. Mixed with more air drawn from the base of the engine, the charge is then admitted to the cylinder through an automatic valve, and the usual cycle carried out. Electric ignition is used, the spark being produced by interrupting the current from a small dynamo, by means of a cam on the distributing shaft.

In the Deutz petroleum engine, as originally made, using oil of 0·80 to 0·85 specific gravity, the lamp for heating the tube and vaporiser was fed by oil vapour from the receiver. The oil was drawn from a reservoir above, in which its level was kept constant, to the mixing chamber, where it was sprayed through a nozzle into a current of warm air. From thence the mixture passed to the vaporiser, a kind of cylindrical jacket over the ignition tube, was evaporated against the hot walls, and entered the cylinder through an admission valve driven by a cam from the side shaft, and acted on by the governor. Ignition by hot tube has now been superseded by magneto-electric ignition in all these engines, with whatever kind of oil or spirit they are driven.

A vertical type introduced a few years ago, to work with petroleum or benzine, has neither side shaft, cams, nor gear wheels. All the valves are automatic except the exhaust, which is driven by an eccentric from the crank shaft. To prevent the valve opening at every revolution, instead of every other revolution, an elastic membrane, acted on by the pressure in the cylinder, connects the exhaust valve to the eccentric. During the compression stroke the pressure sucks forward the membrane, and the valve is held closed. In a later Deutz type the oil is injected through a nozzle by a pump, which regulates the quantity admitted to the vaporiser per explosion. This necessitates a second eccentric on the crank shaft, set in motion by a membrane in the same way as the exhaust valve. During the suction stroke of the piston, the membrane draws forward a hook actuating the oil plunger piston, and the pump sends on the oil, while during the exhaust stroke it is thrown out of gear. As the pump works only in accordance with the pressure in the cylinder, there is no need to regulate the supply of oil by the governor, and the latter acts, therefore, only on the exhaust valve. All the valves of horizontal engines, as now made, are driven by cams from the side shaft. A 4 H.P. stationary engine was exhibited at Berlin in

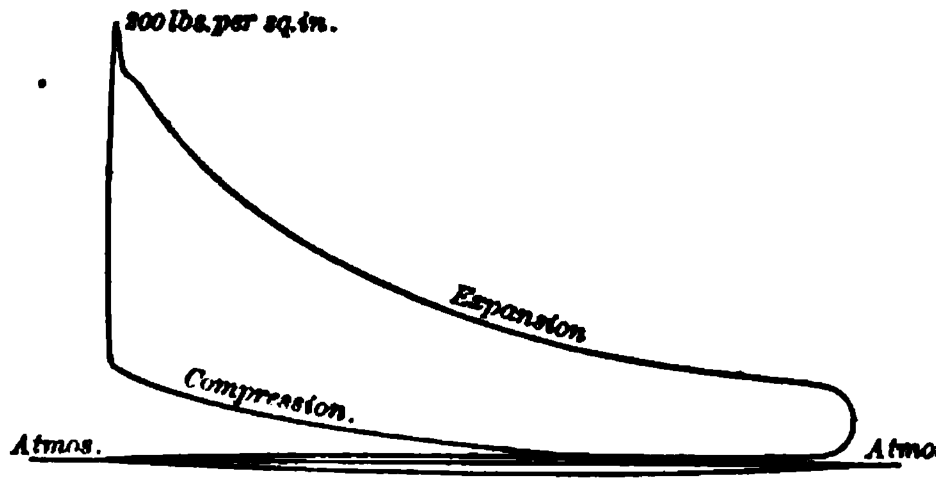

Fig. 151.—Otto-Petroleum Engine. Indicator Diagram.

1894, in which the oil was drawn from a receiver, and the valves were worked by gearing. The 10 H.P. portable engine had a pump which sprayed the oil into air coming through an automatic valve; the action of the pump and admission valve was governed by membranes. The consumption of oil was 0·96 lb. per B.H.P. hour, and speed 297 revolutions per minute. Fig. 151 gives an indicator diagram.

The Deutz firm have also been among the first to bring out portable engines driven with alcohol, one of which was shown at Berlin in 1902, and took the first prize. In this engine the small spirit pump is served by an automatic valve, and its stroke, and thus the quantity of alcohol delivered, can be varied at will. The admission valve and pump are driven by the same stepped cam, and the exhaust by an ordinary cam from the auxiliary shaft. The alcohol is drawn by the pump from a receiver, and injected through a nozzle into the current of air, which effectually breaks it up and pulverises it. As in most of the latest Deutz engines the governor acts on the cut-off, and varies the quantity, but not the quality of the charge admitted. The piston of the alcohol pump and the rod of the admission valve being worked by the same stepped cam, they always move together. If the normal speed is exceeded, the governor shifts the cam through a roller. The pump and valve-rod rise at the same time as before, but close earlier in the stroke —namely, before the dead point—thus the quantity of the charge reaching the cylinder is varied according to the load. No special provision is made for heating either the alcohol or the air. Where the governor throttles the charge, instead of cutting out explosions, previous heating is not found necessary. The cooling water for the engine does not circulate, but is evaporated in a separate vessel, and the supply replenished as required.

Benzine locomotives to run on rails both above and underground are also made. These little engines being self contained, and requiring no ropes or transmission gear, are in considerable request for underground or light railways, or in mines; more than a hundred have been constructed during the last few years. Petroleum or benzine engines are made single cylinder, vertical, from 1 to 20 H.P., with a speed of 380 to 240 revolutions per minute, horizontal up to 300 H.P., running at 250 to 200 revolutions per minute. Portable engines chiefly driven with alcohol are in sizes from 4 to 25 H.P., and benzine locomotives from 6 to 32 H.P. MM. **Langen** and **Wolf**, of Vienna and Buda-Pesth, also make the Otto benzine engine. They construct horizontal motors from 1 to 30 H.P., in which the charge is fired by electricity, benzine portable engines from 3 to 10 H.P., and benzine locomotives for mines. Up to 1903 the Deutz firm had made more than 6,500 petroleum and benzine engines, with an aggregate of 41,000 H.P.

Many trials have been made on Otto oil engines. In 1892 Professor Teichmann tested a 2 and a 5 H.P. motor, in which the consumption of oil was about 1 lb. per B.H.P. hour. An important series of trials was carried out by Herr Meyer at Zurich in 1894 on a 4 H.P. Deutz oil engine. The air for combustion was measured by a meter, to which it was sent through a small fan driven by a turbine, as in Slaby's experiments. From thence it passed to the engine, its temperature in and out of the meter being taken. The quantity of petroleum, of jacket water, temperature of the latter in and out, temperature of the exhaust gases, and volume of the cylinder and compression space, were all carefully determined. The object of the experiments was to ascertain the effect of the speed and of the richness of the charge—that is, the amount of oil per stroke—upon the work, as shown by the indicator diagrams, and their influence upon the moment of explosion, and speed of flame propagation. To obtain the best results from the most diluted mixture in an oil engine, or, in other words, the maximum efficiency with the minimum consumption, Herr Meyer is of opinion that it is necessary (1) to introduce the petroleum into the cylinder in exactly equal quantities per stroke; (2) to vaporise the oil under the best conditions; (3) to bring a fresh and highly explosive mixture, undiluted with the burnt products, into contact with the ignition tube. For particulars of these interesting trials, see *Zeitschrift des Vereines deutscher Ingénieure*, August 17 and 24, 1895. Several tests will also be found in Table 9. A later trial was made by Professor Meyer in 1899 on a 6 H.P. engine worked alternately with benzine and Russian petroleum, in which the consumption of the latter was 0·67 lb. per B.H.P. hour. The engine was governed on the "hit-and-miss" principle. For details see Table.

Benz.—The Rheinische Gas-Motoren Fabrik at Mannheim exhibited a Benz four-cycle engine, driven by light petroleum or naphtha of 0·71 density, at Mainz, in 1893. The naphtha is contained in a reservoir, heated in cold weather with hot water at starting, or by the exhaust gases. Air is drawn into the reservoir and through a layer of naphtha by the suction of the motor piston, and when charged with inflammable vapour passes through a safety valve to another valve admitting it to the mixing chamber. Here the carburetted vapour is diluted with more air, and the charge enters the cylinder through an automatic valve. At the end of the compression stroke it is fired by an ignition tube, heated by a small naphtha lamp. The admission and exhaust valves are driven by rods, cams, and levers from the crank shaft. The engine is governed by cutting out ignitions. If the usual speed is exceeded, the ball governor acts on the admission valve lever, and holds it closed, and air only is drawn into the cylinder, until the speed is reduced.

As the engine is driven by light petroleum, no vaporiser is required. The consumption, as given by the makers, is about 1·1 lbs. oil per B.H.P. hour, with a 4 H.P. engine. This firm has made a speciality of motors for road carriages. A 3 H.P. engine is sufficient to drive a carriage seating four people. These little motors have no governor, the speed being regulated by the driver. Ignition is effected electrically.

Capitaine.—This important engine was one of the first to use ordinary petroleum, and automatic ignition, or firing the charge by the heat in the cylinder only. The patents were originally acquired by MM. Grob & Co., of Leipzig-Eutritsch, who improved it in several respects, and are said to have made the largest number of oil engines in Germany. This firm has now ceased to exist. In 1891 M. Capitaine transferred his patents to Swiderski, of Leipzig-Plagwitz, now the Maschinen-Bau Gesellschaft, who have for the last ten years been represented in England by Messrs. Tolch, of Fulham.

Like the gas engine of the same name, the Capitaine petroleum motor differs in some respects from others, especially in the care taken to stratify the charge as it enters the cylinder. The original four-cycle type and method of construction have with slight modifications been adhered to, as shown in Fig. 152. The diameter of the water-jacketed cylinder is larger than usual, and the stroke shorter. The admission ports are so designed that the charge enters at a high pressure, and is rapidly expanded. The compression chamber is conical. The crank shaft carries a pinion gearing into a wheel of twice the diameter on a horizontal shaft, on which are two cams for opening the exhaust valve, and working the small oil pump. The oil is contained in a tank, into which air at a pressure of 4 lbs. per square inch is sent from a small pump, worked by a bell-crank lever from the cam driving the oil pump. The slight pressure suffices to deliver the oil to the pump, where it is forced upwards by a small piston, through a slide valve which regulates the minute quantity required per stroke. To prevent leakage the little oil pump is filled to a certain height with glycerine, above which the oil floats. The inertia governor is carried on the valve shaft. If the speed is too great, the centrifugal force of the weight acts on a lever arresting the descent of the exhaust valve, and also throws the oil pump out of gear, until the normal speed is resumed.

Above the lamp, at the opposite side of the cylinder to the exhaust, is the vaporiser in which the charge is fired, a small horizontal chamber with external ribs, occupying the same position as the ignition tube (B, Fig. 94), and open to the cylinder without a timing valve. The air is drawn into the cylinder, through the automatic valve at the top, by the suction of the piston. A minute quantity of oil sent on from the petroleum pump is sucked in at the same time, carried with much force

through the red-hot vaporiser, and completely vaporised. As it issues out into the cylinder, it meets the air entering at right angles, and the two are compressed by the return stroke of the piston, driven up against the walls of the vaporiser, and fired, the heat generated by the compression stroke, and the addition of air, making the charge inflammable. The temperature of the vaporiser is maintained by a lamp beneath it, fed with oil from the tank, in the same way as the

Fig. 152.—Capitaine Oil Engine.

oil pump. This lamp forms an important part of the engine, and should always burn with a bright blue flame. It is provided with a long bent tube, at the end of which is a conical burner with a very small hole; the flame of the burner evaporates the oil both in the vaporiser and in the tube itself. In the earlier oil engines, the flame also played upon the small ignition tube, but it was accidentally discovered that, after running some time, the engine would work without a light, and all

external lamps are now dispensed with, except at starting. In place of a chimney to the lamp there are two iron capsules with asbestos joints. In one type of the engine these capsules expanded, if the vaporiser became too hot, and allowed the external air to enter, and act upon its surface. In another arrangement the temperature of the vaporiser was made to regulate the flow of oil to the lamp. The cover of the vaporiser was held against it by a spring, and on the slightest expansion, due to overheating, the spring acted upon a membrane valve in the oil admission pipe, and checked the supply. To start the engine, the exhaust valve is held open during the compression stroke, and the flywheel turned with a hand crank, which falls out of gear automatically when the engine is at work. The tube of the lamp and the vaporiser are heated by a spirit lamp at starting.

In the **Swiderski** (Capitaine) engine worked with alcohol, one of which was shown at Berlin in 1902, the spirit is contained in a small receiver always open to the suction passage. The level in this receiver is kept constant by a float and a needle valve, and only so much alcohol is allowed to pass into it from the supply tank as is required to form an explosive charge in the cylinder. The quantity is regulated by a screw. A carburator of the Longuemare type is used, and the exhaust gases carried round it, to heat the spirit; the air for pulverising the charge can also be previously warmed by the hot products. The alcohol is drawn with considerable force, by the suction of the piston and the vacuum thus produced, into the carburator, together with a small quantity of air entering at right angles to it, and broken up by passing through holes and baffle plates. More air is then added, and the carburetted charge, thoroughly mixed by the rapid motion imparted to it, is swept into the cylinder. The engine is governed on the "hit-and-miss" principle, in the same way as other types of the Capitaine. The exhaust valve only is worked from the side shaft, the admission valve is automatic. The motor is started with benzine.

The Capitaine engine has been shown at most exhibitions of late years, and was one of the best of those at the Berlin trials of 1894, where two vertical portable engines were exhibited. In a trial of a 10 B.H.P. engine at Leipzig in 1893 the oil consumption was 1 lb. per B.H.P. hour. The engine is made vertical, with one, two, or four cylinders, in sizes from 1 to 60 B.H.P., with a speed of 360 to 250 revolutions per minute. For boats two cylinders are used. It is also largely made as a portable engine for pumps, locomotives, driving dynamos, and many other purposes, and about 600 engines have been supplied for marine work. Several tests will be found in Table 9.

Bánki.—This important oil engine, constructed by Ganz & Co., of Vienna and Buda-Pesth, on the Bánki-Czonska system, is extensively

used in Austria and Hungary, especially for agricultural and other industrial purposes. It is of the usual four-cycle type, may be driven with either benzine or ordinary petroleum, and can also be modified to

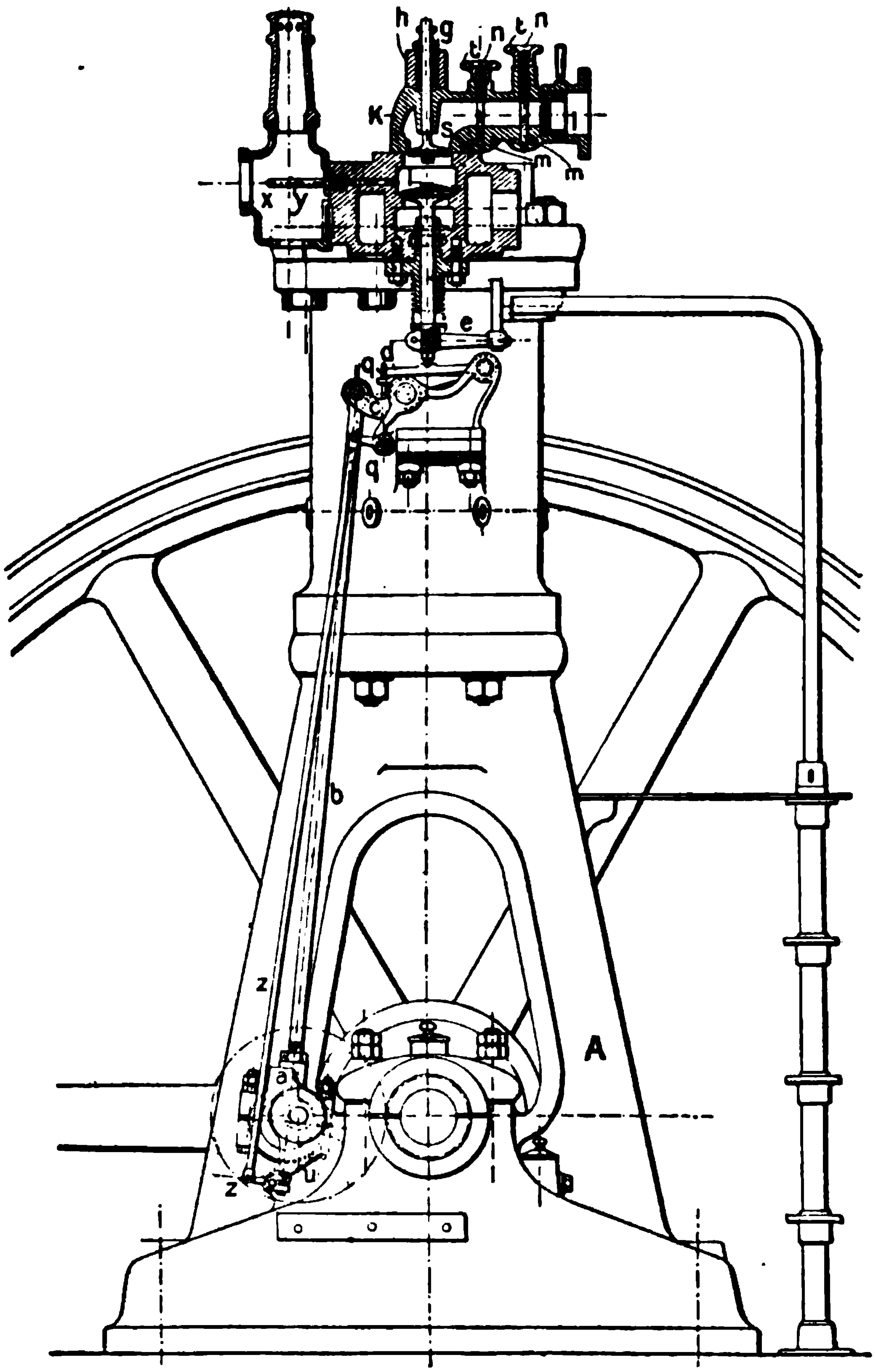

Fig. 153.—Bánki Oil Engine—Sectional Elevation.

work with lighting gas. It has lately (1905) been adapted for use with alcohol.

Professor Bánki, who has made several valuable contributions to our scientific knowledge of oil engine cycles, has in this motor introduced

a new method of forming the explosive charge. Proceeding on the now well-established fact that the true means of increasing the efficiency of an engine is to be sought in greater compression of the charge, he justly observes that as compression is increased, the temperature of the explosive mixture will be raised, and more trouble will be caused by premature ignitions. To avoid this difficulty, the air and combustible must be separately compressed, as in the Diesel engine, or the oil admitted only after compression, as in the Hornsby. Another way which, according to Bánki, increases instead of diminishing the efficiency, is to cool the charge itself, and this he has done by a novel method of injecting water. Hitherto the injection of water into the cylinder of an internal combustion engine has not generally been advantageous, because the object was to increase the pressure by evaporation, and not, by reducing the temperature, to obtain higher compression. In Bánki's system the water is introduced in a very fine spray, and thoroughly mixed with the oil and air, in accordance with these conditions.

Figs. 153 and 154* show the construction of the engine, K is the exhaust valve, which is driven either by an eccentric or by a cam and roller from the valve shaft, geared 2 to 1 to the main shaft. The suction valve S is automatic in the smaller engines; for larger powers this valve also is worked from the cam shaft. The lamp y heats the vaporiser and the hot tube x, which is open to the cylinder without a timing valve, and the exhaust gases are also carried through the upper part of the vaporiser, to heat it. It has now been found possible to dispense with the lamp after the engine is at work, the heat generated by the motor itself being sufficient for the vaporisation and ignition of the oil. This automatic action is said greatly to conduce to the efficiency of the engine, the constant attention formerly required by the lamp being now no longer needed. The ignition is as punctual as when electricity is used. The "hit-and-miss" governor, consisting of two centrifugal weights, is also on the cam shaft, and acts on the exhaust valve by holding it open, if the normal speed is exceeded.

The method of spraying the oil and water is original. In the valve chamber L (Fig. 154), which also acts as the vaporiser, is a vertical screw forming a pulveriser, through the centre of which a small hole is pierced. The conical base of the screw abuts on a receiver filled with oil up to a level kept constant by a float. Air is drawn down through the central hole of the screw by the suction of the piston at each stroke, and the oil at the base is suddenly sprayed out on either side through a nozzle, by the force of the air current, and thrown against the sides of the chamber. It is next broken up by another blast of air admitted at right angles, and

* Reproduced by kind permission of the Editor from an article by the Author on the Bánki engine, in *The Engineer*, March 21, 1902.

vaporised by the heat, and the charge passes to the cylinder through a mechanically-driven valve. The same arrangement is made to admit the water. The two pulverisers for the oil and water are placed in the ad-

Fig. 154.—Bánki Oil Engine—Sectional Elevation.

mission pipe, each being connected to a receiver with a float, to regulate the level. At *m m* (Fig. 153) are seen the two nozzles, and the screws for

regulating the quantities passing to the admission valve are shown at *n n*. The air valve being opened, the air passing to the oil pulveriser is moistened with fine particles of water, and it is into this damp air that the oil is sprayed in the form of mist. As the quantity of oil per stroke depends on the air passing through the centre of the pulveriser, and hence on the vacuum in the cylinder, the composition of the charge is said to be always uniform. The two pulverisers may be interchanged, and the air first saturated with petroleum, then charged with water. If the engine is worked with lighting gas, acetylene, &c., the pulveriser must be replaced by a mixing apparatus for gas and air.

This system of water injections with oil engines was tested by Prof. Bánki at MM. Ganz's works, and the experimental four-cycle engine to which it was applied ran well and quietly, although the compression space was greatly reduced, but when the water was shut off there were violent explosions. The consumption of oil was also much less with the water injections. A 20 H.P. engine, with a piston diameter of 9·1 inches and 15·7 inches stroke, has been made, and tested with the apparatus at Buda-Pesth. Ignition in this motor is by hot tube without a lamp, and the mixture of air and pulverised oil and water is compressed to 13 atmospheres. The heat of compression evaporates the water, and combustion produces superheated steam at 30 atmospheres pressure, which by its expansion increases the work done. The engine is said to consume 250 grammes = 0·55 lb. of oil per B.H.P. hour, and with a mean pressure of 10 atmospheres the consumption was even reduced to 208 grammes = 0·45 lb. per B.H.P. hour. Tests on several small Bánki engines have been made by Professor Meyer, and one was carried out in 1901 by Professor Schimánek on a 16 H.P. benzine engine, in which the maximum compression pressure was 234 lbs. per square inch, and the heat efficiency per B.H.P. 28 per cent. This striking result with so comparatively small an engine is attributed to the water injections, which allow of a much higher compression of the charge than usual. A series of five trials were also made on a 20 H.P. engine by Professors Jonas and Taborsky, details of which will be found in the Tables. In this engine also 28 per cent. of the heat given to the engine was turned into actual work. A full account of these interesting tests will be found in the article in *The Engineer*, already referred to. The engine is made vertical only, in sizes from 5 to 50 H.P., with a speed of 300 to 120 revolutions per minute. It is also made as a portable engine, and for driving light locomotives. In the largest sizes two cylinders are used.

Diesel.—Perhaps no engine has made more stir, or raised greater expectations in German scientific circles of late years, than the Diesel "Rational Heat Motor." The inventor, instead of constructing an engine, and deducing a theory from it, first laid down the working

principles which, in his opinion, ought to govern any improvement in our present internal combustion engines, and then proceeded to embody them in practice. These fundamental principles are set forth in detail in a book, *Theory and Construction of a Rational Heat Motor* (J. Springer, Berlin, 1893), (an English translation of which has been published by Spon), and may be summarised as follows:—

(1) Production of the highest temperature of the cycle, not by and during combustion, but before and independently of it, entirely by mechanical compression of the air.

(2) Gradual introduction of a small and carefully-regulated quantity of finely-divided combustible into the highly-compressed and heated air, in such a way that no increase of temperature takes place during the motor stroke, but all the heat generated is at once carried off by the expansion of the gases of combustion.

(3) Introduction of a large quantity of air in excess, instead of admitting only as much air as is required to obtain proper combustion of the fuel in the cylinder. This condition rests on the principle that the quantities of heat contained in oil or other combustible are too great to be utilised in an engine cylinder, unless there is a large excess of air—say 100 per cent. to carry it off.

It will be seen that the working cycle thus obtained differs in several respects from that usually carried out in gas and oil engines. It conforms more closely to the theoretical Carnot cycle than any other, and therefore the progress of the Diesel engine has been followed with close interest by scientific men, including Professors Schröter, Slaby, Gutermuth, and others, in Germany and elsewhere.

As originally designed the Diesel engine had three vertical cylinders side by side, the ordinary cycle of work, admission, compression, ignition and expansion, and exhaust being divided between them. To carry out the perfect Carnot cycle Diesel proposed to have first isothermal compression, to be obtained by injecting water to carry off the heat, and then adiabatic compression. Further, he hoped to obtain such complete expansion that no cooling jacket would be required, but all the heat generated would be expended in work. This latter principle, the unattained ideal of inventors for so many years, was soon found impossible. A water jacket became necessary, and isothermal compression, with pressures of 250 atmospheres, was abandoned in favour of adiabatic compression only, which required pressures of from 30 to 50 atmospheres. Although Herr Diesel hopes ultimately to work with different power agents, at present the engine has only been driven with oil of various kinds, alcohol and spirit, but experiments with lighting and cheap gas are in progress.

As made by the Augsburg Maschinen-Fabrik, MM. Krupp, of

Fig. 155.—20 Horse-power Diesel Oil Motor.

Essen, and several other firms, the engine is four-cycle, vertical, single-acting, with small auxiliary oil and air pumps, and the water jacket now admitted to be indispensable. The original experimental engine is said to have worked without it, and also without an air reservoir, but both have been added to the motor shown at Figs. 155 and 156. There is no ignition device of any kind, nor is the fuel compressed, the compression stroke acting on the air only. B is the valve shaft worked by gearing from the crank shaft through a vertical shaft 2 to 1, and from it the admission valve V_1, the exhaust V_2, and the oil pump are driven; *d* is the crank shaft, P the motor piston working downwards on to the crank, and *c* the water jacket. The motor piston draws in a charge of air at atmospheric pressure, and compresses it in the up-stroke. The air for spraying the oil is drawn into the pump Q, worked by levers *z* and X from the connecting-rod, and compressed into the reservoir L at the side, where it is at a pressure of 35 to 50 atmospheres. From thence it passes

Fig. 156.—20 Horse-power Diesel Oil Motor.

through pipe S and valve V_1 to the valve chamber D at the top of the cylinder, where a very small quantity of oil is injected into it through the nozzle *n*, and gradually ignited by the heat of the highly compressed air. By means of the pipe S the pressure is also equalised between the reservoir, air pump, and valve chamber D. For starting the engine, the cams actuating valves V_1 and V_2 are thrown out of gear by moving a lever, and air from the reservoir L is admitted through a special starting valve. Combustion is regulated by varying either the time during which oil is injected, the period of admission, or the pressure in the air reservoir. Connected to the injection nozzle are two valves, the admission and an overflow. The descent of the little oil pump piston closes the latter, and sends the oil to the valve chamber D. But if the normal speed is exceeded, the governor interposes a wedge below the oil piston, the overflow valve remains open, more or less, and part or the whole of the oil passes back to the receiver.

From this description it will be seen that the ordinary four-cycle is adhered to, but the dimensions are very small for the power developed. Herr Diesel has given many years to the study of the subject, and his method of treating the oil is founded on mature experience. He does not allow it to come in contact with the cold cylinder walls, nor is it previously vaporised, and thus separated into its heavy and volatile constituents, but it is injected in a liquid state and at once into the body of compressed air, and the whole instantly vaporised and burnt, before it has had time to condense against the walls. Combustion is independent of the speed of propagation of the flame, because each particle of oil as it enters finds sufficient air for its combustion. Another merit of the engine is the very high compression of the charge, much higher than in other oil engines. These pressures occasioned much difficulty with the valves at first. The temperature of combustion appears to be really obtained, as the inventor claims to obtain it, before and independently of combustion. As air is the only agent in producing this result, there is no danger of premature ignition, such as may happen in an engine where oil and air together are highly compressed, and miss-fires are impossible. No light of any kind is required, the oil being wholly vaporised by the air under pressure. As a result a theoretical heat efficiency of 50 per cent. was expected, and an indicated heat efficiency of 34 to 40 per cent., with a corresponding reduction in the consumption of oil, has been actually obtained.

Several interesting novelties have during the last few years been introduced, chiefly by the able and enterprising directors of the Augsburg Maschinen-Fabrik, to whom the credit of overcoming the initial difficulties, and of much valuable work in perfecting the engine is due. The chief improvements are in the pulverisation of the oil, regulation

of the supply by the governor, and the compression. The latest pulveriser consists of four circular discs set one above the other, pierced with alternate holes, through which the current of air draws down the petroleum, and breaks it up against the discs. As the air is at a high pressure, and the holes are comparatively large, they do not get stopped up, as was the case when the oil was passed through a sieve. Of the two valves, suction and delivery, of the little oil pump, the delivery valve to the cylinder is always automatic, and its lift does not vary, but it cannot rise until the suction valve, which draws the oil from, and returns it to the receiver, is closed. This inlet valve, worked by a small crank on the valve shaft, is now connected to the governor by levers moving on a pivot. If the load varies, the governor draws up the pivot and levers, the suction valve is closed later, and opens sooner, and thus the quantity of oil sent to the cylinder is reduced.

A third novelty is that the air pump draws air, not from the atmosphere, as before, but from the motor cylinder through a small discharge valve opened during the latter half of the compression stroke, when a pressure of 150 lbs. per square inch has been attained. The air passes into the passage serving to admit compressed air to start the engine, and is sucked from thence by the air pump, compressed to 60 atmospheres (850 lbs. per square inch), and delivered to the admission valve, where a very small quantity of petroleum is injected into it; the rest of the cycle is as described. A valve on the air pump regulates the supply of air according to the pressure in the cylinder. Thus the pump has to compress the air to one-sixth instead of one-sixtieth the original volume, and its dimensions can be proportionally reduced. The air pump of a 30 H.P. engine is 2 inches in diameter, with 3 inches stroke.

Trials.—Herr Diesel maintains that his engine works with a lower consumption of oil than others, and this seems to have been confirmed by a large number of tests. A careful series of trials was made on a 20 H.P. engine by Professor Schröter at Augsburg, in February, 1897. The cylinder diameter was 9·8 inches, stroke 15·7 inches, and the engine ran at 154 revolutions per minute. It indicated 24·7 H.P., with a consumption of 0·39 lb. of oil per I.H.P. hour, and gave on the brake 17·8 H.P., with a consumption of 0·52 lb. of oil per B.H.P. hour. The heating value of the oil used was 18,370 B.T.U. per lb.; mechanical efficiency, 75 per cent.; the large negative power required to drive the high pressure air pump reduced this efficiency. The heat turned into actual work on the brake was 26·8 per cent. of the total heat given to the engine; another test gave 25·8 per cent. This high heat efficiency is attributed by Professor Meyer, not to combustion at constant temperature, to which Herr Diesel ascribes it, but to the high pressures

attained. Another trial was made by Professor Meyer on a 30 B.H.P. engine in September, 1900, in which the consumption of American oil was 0·44 lb. per B.H.P. hour, and the high heat efficiency of 30 per cent. per B.H.P. was obtained. Two important trials were made by him in 1902 on a 70 B.H.P. and an 8 B.H.P. engine, driven with Russian petroleum and cheap paraffin oil from German brown coal. The heating value of the Russian oil was 18,540 B.T.U. per lb., and of the paraffin 2½ per cent. less. The heat efficiency of the larger engine per B.H.P. at normal load was 32·1 per cent., and of the smaller 27·6 per cent.

Several valuable trials on the Diesel engine have been made by Mr. Ade Clark, who has written an able paper on the recent developments of the motor.* A 35 B.H.P. engine was tested by him in England in 1902, and one of 80 H.P. and another of 160 H.P. at Ghent in 1903. American oil was used in the English trials, and the heat efficiency of the engine per B.H.P. worked out at 28·7 per cent. At full load the heat efficiency of the 80 H.P. was 31·2 per cent., and of the two-cylinder 160 H.P. engine 32·3 per cent. The consumption of oil per B.H.P. hour varied from 0·8 lb., in the smallest, to 0·4 lb. in the largest engine. The utmost care was bestowed on these exhaustive and excellent tests. Particulars of most of the above trials will be found in the Tables.

The Diesel engine was first shown at the Munich Exhibition of 1898, when motors of various powers were exhibited by the original makers, the Maschinen-Fabrik Augsburg, and three other leading German firms; all were single-cylinder engines, driven with ordinary oil. It has now found wide application in many countries. In Russia it is much used, because of its easy adaptability to any kind of oil, and Diesel engines are working in Siberia and Turkestan. The electricity for driving the street tramcars in Kieff is supplied by four sets of Diesel engines, each of 500 H.P. Each set consists of four motor cylinders, with a speed of 160 revolutions per minute, and a working stroke is obtained in one or other cylinder at every half revolution. The air pump in the Russian engines is single-, instead of double-acting. These engines are also used to pump the oil through the pipe lines from Baku to Batoum on the Black Sea. Water being scarce, the water for the cylinders is cooled by an air current created by the pressure of oil, on the system of contrary currents. In America the engine is made with three cylinders up to 1,000 H.P., and a usual arrangement is to have several separate engines in one factory, served by a common air pump, oil tank, and oil pump. The same method is adopted in Sweden for three cylinder engines. A marine type for a canal boat has been brought out by MM. Sautter and Harlé, of Paris, in which the two cylinders are arranged horizontally,

* *Proceedings of the Institution of Mechanical Engineers*, July, 1903.

with the crank shaft between them. In the Hungarian type made by the Maschinen-Fabrik Buda-Pesth, the exhaust valve, oil pump, and governor are driven from the valve shaft by a single disc carrying the cams arranged in three concentric circles. Oil made from earth nuts, which grow in profusion in the French African Colonies, has also been used as the motive power. The engine is made single cylinder from 8 to 150 H.P., with a speed of 270 to 150 revolutions per minute, with two cylinders from 30 to 300 H.P. In Germany it is constructed chiefly by the Vereinigte Maschinen-Fabrik Augsburg and Maschinen-Bau Gesellschaft Nuremberg; in Russia by Ludwig Nobel; in Belgium by Carel Frères of Ghent; and in England by the Diesel Engine Company. The Augsburg firm alone have since 1898 supplied over 400 engines, with a total of 22,000 H.P. Of these 7,370 H.P. were for Germany, 13,000 H.P. for Russia, and 1,630 H.P. for other countries. The author saw many of these motors at work, and they ran very quietly and easily. Full details, and an account of Professors Schröter and Meyer's trials will be found in *Zeitschrift des Vereines deutscher Ingénieure*, July 10, 17, 24, 1897, and Nos. 18, 19, 24, 27, 1903. An application of the entropy diagram to a Diesel engine will be found in the same periodical, September 24, 1898.

The **Kjelsberg** (1889) petroleum engine, constructed by the Schweizerische Maschinen-Fabrik Winterthur, and MM. Nobel Bros., of St. Petersburg, was tested at Meaux in 1894 (see Table 9). It is a carefully designed single-cylinder motor of the four-cycle type, and is made in sizes from 2 to 35 H.P., both vertical and horizontal; it runs at 250 to 170 revolutions per minute. In the vertical engine the oil passes by gravity to the valve chamber from a reservoir above, through a pump driven by the cam shaft, the stroke of the pump regulating the quantity (about one-twelfth of a gramme). The air is drawn in through an automatic valve lifted by the vacuum in the cylinder, which thus determines the quantity admitted. The speed of the air is sufficient to spray the petroleum, and the latter is also broken up by falling over a cone into the vaporiser below, a vertical cylindrical tube, with a jacket through which the hot gases circulate from a lamp heating the ignition tube. As the gases ascend, while the oil is carried down through the vaporiser by the current of air, complete and rapid vaporisation is said to be obtained by means of contrary currents, a principle utilised in several German engines. The vaporised charge is then admitted to the cylinder through a valve worked by levers and cams from the auxiliary shaft. Ignition is by a small brass tube without a timing valve, heated by a lamp which also heats the vaporiser, and is usually fed by a branch pipe from the main oil supply. The small orifice of the tube prevents ignition till the end of the compression stroke. The oil pump is con-

nected to the admission, but acts for a shorter time per stroke, to ensure a sufficient supply of air through the automatic valve to break it up thoroughly. The rotary ball governor on the crank shaft regulates the admission of oil in accordance with the load. The consumption is from 0·8 to 1 lb. petroleum per B.H.P. hour.

In the vertical 5·2 B.H.P. engine exhibited at Meaux the consumption was 0·84 lb. per B.H.P. hour, at a speed of 226 revolutions per minute. Experiments made in St. Petersburg on a 3½ H.P. motor, showed a consumption of 1·1 lbs. per H.P. hour of oil of 0·82 density. Russian oil is used by preference in this engine, especially that of the Nobel brand. About 800 motors have been made; the author saw several at work.

The well-known firm of **Nobel** in St. Petersburg also made portable oil engines of their own design for some years. In these the exhaust, admission, and oil valves were all connected, and when the centrifugal governor acted upon the former, all three were held closed. The oil was drawn under pressure from a receiver by a plunger pump worked from the valve shaft, forced into the air chamber, where the level was maintained constant by a float, and thence to the admission valve of the engine. A small rotary pump circulated the cooling water. The consumption of oil of 0·81 specific gravity was 1·4 lbs. per B.H.P. hour in an 8 H.P. engine. MM. Nobel are now makers of the Diesel engine.

The firm of **Bechstein** in Altenburg make horizontal and vertical four-cycle engines for use with benzine, alcohol, or heavy petroleum, chiefly the lighter oils. The valves are driven by cams from the lay shaft in the usual way. No vaporiser is required with benzine or alcohol; the spirit is drawn, cold, from an air-tight receiver, through which a blast of air, regulated by the suction stroke of the motor piston, is passed. The air becomes saturated with the benzine in its passage, and the explosive charge is thus generated per stroke as required. The receiver is filled at starting from a small pump; the consumption of benzine is said to be about 1 lb. per B.H.P. hour. Some engines are fitted with a carburator, in which the benzine is pulverised, before mixing it with the air. When ordinary petroleum is used, a small quantity is regularly drawn per stroke, and sent to the vaporiser from the receiver by a little plunger pump. The vaporiser is heated by a lamp. The governor acts on the admission valve, and regulates the consumption of oil according to the load. Ignition in engines driven with light oils is generally electric, to avoid the danger of an external flame, but engines up to 4 H.P. have hot-tube ignition. For benzine and alcohol the engines are made vertical from ½ to 4 H.P., and run at 450 to 500 revolutions per minute, horizontal from 1 to 20 H.P., with

a moderate speed of 250 to 160 revolutions per minute. Portable engines are made in eight sizes, from 2 to 12 H.P.

The construction of several small oil engines—viz., the **Molitor, König Friedrich August Hütte, Bütske, Sachsenburger Maschinen Fabrik, Hermann, Januschek,** and **Waibel**—has now been given up. A description of them will be found in the Third Edition of this book. German engine builders appear to devote more attention to the manufacture of engines to be driven with light volatile oil, benzine, alcohol, &c., than ordinary heavy petroleum, and the former class of motor is in great and increasing demand for portable engines, threshing, rolling, small manufactures, &c.

Hille.—The **Dresdener Gas-Motoren Fabrik** (Hille's patent) have frequently exhibited oil engines in sizes varying from 1 to 8½ B.H.P., and a stationary and a portable engine at Berlin in 1894; they have, they say, 5,500 of their oil and gas motors at work. Like many other German firms they make several classes of oil engines, for use with heavy petroleum, benzine, alcohol, and acetylene. Ignition is by hot tube in the petroleum motors. The oil falls from a receiver above to a double-seated automatic valve, which, when lifted by the pressure in the cylinder, allows a current of air to enter, and carries with it the small valve admitting oil through a nozzle or holes into the valve chamber below. The latter, which also serves as the vaporiser, is placed immediately over the ignition tube, and both are heated by the same lamp. The charge of oil vapour and air passes thence to the cylinder through the admission valve, upon which the governor acts by a hit-and-miss arrangement, to regulate the speed. Usually the admission valve is opened from an intermediate shaft running at half speed, by a cam and levers, which act on a collar and knife edge sliding up and down the valve-rod. If the normal speed is exceeded, the governor brings another projection into play, and causes the knife edge to miss the opening of the valve. The admission and exhaust valves are held on their seats by springs, the exhaust being the weaker spring of the two. If the admission is held closed by the governor, the exhaust is automatically lifted by the pressure in the cylinder, and only burnt products are re-introduced until the speed is reduced. In another method the governor interposes the knife blade below the exhaust valve-rod, and thus prevents it from closing. A second cam on the intermediate shaft holds open the exhaust during the compression stroke, when starting the engine. In the vertical type the air and oil are introduced in the same way as in the Capitaine and the Seck. A small quantity of oil is sent by a pump, together with a little air, into the vaporiser, a horizontal chamber heated by a lamp, at the side of and open to the cylinder. More air is added through an automatic valve at the top, and it is the addition of this air which renders

the charge inflammable. The next compression stroke drives the mixture back into the vaporiser, where it is fired, and the usual cycle carried out.

In the benzine motor the volatile oil is vaporised in an apparatus similar to that in the Deutz-Otto engine, shown at Fig. 150. A small pump is used to fill the receiver, and air is drawn through it by the suction of the piston, and passes to the engine saturated with oil vapour. The mixture requires to be further diluted with air before the charge is fit for use. Safety valves and wire gauze prevent the flame from striking back to the receiver, and the carburetted air is also drawn through a layer of pebbles on its way to the motor. The receiver is heated by hot water at starting, and the exhaust gases can also be utilised for this purpose, if necessary.

At the Berlin trials of 1902 an engine driven with alcohol was shown by the Dresdener Fabrik. In this type the alcohol and air are admitted through an automatic valve opened during the suction stroke by the vacuum in the cylinder. The current of air is drawn in at right angles to the alcohol, and pulverises it; the receiver is surrounded by a jacket, through which the cooling water at a temperature of 140° F. is led, and the alcohol thus heated before admission. The quantity passing to the cylinder per stroke is regulated by a screw at the junction of the alcohol and air passages. Governing is on the "hit-and-miss" principle. The engine is made horizontal, in sizes from 1 to 50 B.H.P., vertical from 1 to 8 H.P., and runs at 250 to 150 revolutions per minute. The portable type is made from 2 to 12 H.P. (see Tests, Nos. 47 and 58, Table 9).

Lützky.—The vertical benzine motor, formerly made by the Maschinen-Bau Gesellschaft Nuremberg, was similar to the Lützky gas engine, with the addition of a vaporiser. The benzine was conveyed to the engine in a liquid state, and evaporated per stroke as required. The air was drawn in by the suction of the piston. The oil was injected on to a small wheel with vanes, inside the mixing chamber, which, being kept in rapid motion by the current of air, caught the benzine as it fell, sprayed it into the air, and the two were thoroughly mixed. The charge then entered the cylinder, and was compressed, ignited, and discharged in the usual way. In the 6 B.H.P. engine exhibited at Erfurt the consumption was 0·88 lb. of oil per B.H.P. hour, and the speed of the engine 190 revolutions per minute.

The **Buda-Pesth Maschinen-Fabrik** formerly made vertical engines on Scherfenberg's patent, of the usual four-cycle type, worked with ordinary petroleum; but their construction has now been given up. A description will be found in the Third Edition. This firm is now affiliated to the Augsburg Maschinen-Fabrik, and are makers of the Diesel engine for Hungary.

Dopp.—The oil engine made by Herr Dopp, of Berlin, is vertical, in sizes from 1 to 12 H.P. Herr Dopp, who has studied the theory of internal combustion motors, constructs his engines on a well thought out and somewhat novel principle. No attempt is made to pulverise the oil, as is usually done. Each charge of liquid oil is separately converted into vapour without any air, and highly superheated, before it is admitted in finely-divided currents to the combustion space, and mixed in the usual way. The air for combustion cools it a little, but it is already at so high a temperature, and so short a time is allowed for ignition, that the oil vapour does not fall to condensation point. In his paper Herr Dopp notes the regularity of the combustion obtained by this method, as shown by indicator diagrams, twenty of which covered each other, thus proving the purity of the charge. Even with 20 per cent. miss-fires, similar diagrams were obtained. The quantities of air and of combustible are carefully regulated, and do not vary. A small sensitive oil pump, with adjustable screw, sends on the liquid oil to the vaporiser through a hopper, the feed of which is visible. The exhaust can also be seen, and the composition of the burnt products affords a reliable indication of the combustion, whether perfect or not; thus the engineer can regulate the whole process. In the engine shown at Berlin in 1896, the exhaust was found to be quite clean. Experiments by the makers on a 6 B.H.P. engine gave a consumption of 0·53 lb. of oil per B.H.P. hour, a very good result when the size of the engine is considered. A 10 B.H.P. engine, officially tested, gave a consumption of 0·43 lb. oil per B.H.P. hour, including the oil for the lamp. According to the inventor, the cleanliness obtained in the cylinder is even more important than the low consumption of oil, and he cites a 2 H.P. engine which, when at work, did not require cleaning for a year and a half. The engine is said to work quietly, with great regularity, and without vibration. It is made in sizes from 1 to 20 H.P., with a speed of 360 to 220 revolutions per minute, and is one of the few German engines adapted to work with ordinary petroleum. It is also driven with benzine and alcohol.

Russian Engines.—Special attention has of late years been paid in Russia to oil motors, and many, all of German type, were shown at the Nishni Novgorod Exhibition in 1896. A vertical two-cylinder engine by **Bromley,** of Moscow, had an enclosed base partly filled with oil, into which the crank dipped, and lubricated the engine. The motor was of the usual type, with vertical valve shaft driving the exhaust and oil pump, the air and admission valves being automatic. The oil entered from above, and drew a small quantity of air with it into the vaporiser, which was heated at starting by a lamp, afterwards only by the heat of explosions. The bulk of the air entered below, the compression stroke drove the charge back into the vaporiser, and ignition followed.

A piston valve forming the oil pump sent on a given quantity of petroleum to the mixing valve from a receiver, where it was maintained at a constant level. The governor acted by varying the stroke of the pump. A 7·64 B.H.P. engine was tested by Professor Zernow, in which the consumption was 1·1 lbs. oil per B.H.P. hour.

MM. **Liphardt**, of Moscow, have also made oil engines, both stationary and portable, of the Altmann type. This firm is well known in Russia as makers of agricultural motors; their portable engines are of the usual kind, with cooling water arrangements on the Grob system. In the vertical engine the valve shaft drives the exhaust and admission valves by cams. The oil passes from a Marriotte bottle, where the pressure is always constant, to the cylinder, is vaporised against the hot walls of the compression space, and fired on reaching the ignition tube. The latter is heated by a lamp fed with oil from a separate receiver, and has no timing valve. There are auxiliary cams to start the engine, and the Porter governor acts on the exhaust. This engine was also tested by Professor Zernow, and gave a consumption of 1·3 lbs. oil per B.H.P. hour. A similar engine was exhibited by **Jakowlew**, of St. Petersburg, and a motor of the Altmann type was also shown by **Machtschinki**, of Warsaw. The **Kablitz** is another small oil engine, made both two- and four-cycle, but Russian engine builders seem of late years to have devoted more attention to the development of German engines, as the Diesel, Koerting, &c.

Pétréano Vaporiser.—One of the defects of internal combustion engines, which has not been wholly overcome, is the imperfect mixing of the charge, causing after-combustion. M. Pétréano, who is an authority on the subject, maintains that, if the mixture of gas or oil and air be properly prepared, the flame often seen at the mouth of the exhaust valve disappears, because combustion is completed at the moment of explosion. The charge should be perfectly mixed before entering the working cylinder of an engine, as combustion proceeds so rapidly afterwards that no mixing is possible.

To remedy the defect of imperfect mixing, M. Pétréano introduced a carburator or vaporiser, consisting of a vertical cylindrical vessel, through the centre of which a pipe carried the hot exhaust gases from the engine, to discharge to atmosphere. This pipe was surrounded with wire gauze, and the annular space between the gauze and the outer walls of the vaporiser was divided into compartments by diagonal wire gauze funnels, connected alternately to one or the other side. The oil or other liquid dropped into the top of the vaporiser, and drew in with it a sufficient supply of air to break it up. The mixture was carried downwards, then upwards, through and between the funnels, and the oil first vaporised by contact with the hot wire, then broken up and thoroughly mixed with

the air, by the eddying motion produced by the openings in the funnels. The quantities of oil and air admitted were carefully regulated; the heavy residuum drained off down the funnels to the bottom of the vaporiser. This apparatus was tested with Dr. Slaby's experimental 16 H.P. Otto engine in the Charlottenburg Laboratory in 1897; 24 H.P. was obtained on the brake with the Pétréano vaporiser, or 50 per cent. increase in power, and the consumption was 450 litres = 14·8 cubic feet of gas per B.H.P. hour. A stronger and more certain explosion was procured, and the explosive pressure, as shown by the indicator diagrams, rose from 9 to 12 atmospheres = 128 to 170 lbs. per square inch. According to M. Pétréano, the speed depends on the composition of the charge, because with the usual method time must be allowed for combustion during the stroke, but with a perfectly-mixed charge combustion is instantaneous, and no such interval is required.

The principle of this apparatus has been more or less adopted in several modern vaporisers, but it does not seem to have found much favour as a separate carburator, and the economy claimed for it is hardly realised when the vaporiser is applied to engines of modern type.

CHAPTER XXIV.

PRACTICAL APPLICATIONS OF GAS AND OIL ENGINES.

CONTENTS.—Electric Lighting—Stations in England and Abroad—Waterworks—Tramways driven by Gas—Gas Engines for Electric Traction—Boats for Rivers and Lakes—Capitaine—Daimler—Priestman—Vosper—Griffin—Foreign Marine Engines—Portable Engines—Trials at Berlin—Meaux—Cambridge—Second Berlin Trials—Road Motor Cars—Daimler—Roots.

A GREAT impulse has been given to industrial development by the application, to many purposes, of engines driven by lighting, power, and blast-furnace gases, and by oil. The advantages of these motors over steam for small powers, or where motive force is only required intermittently, have been manifest for many years. It remains to summarise and recapitulate the uses to which the power thus obtained has been applied, and these are so many and varied that the extensive utilisation of gas and oil engines has produced a great change in our present system of generating power. It has been said by more than one student that the nineteenth century was the age of steam; the twentieth will probably witness the evolution of the gas engine. In the extraordinary development of large power engines driven with cheap or poor gas, the Germans and the Cockerill firm at Seraing may be said to have been pioneers; while in France, and especially in England, the construction of engines of medium size, driven sometimes interchangeably with oil or gas, has greatly increased. Hundreds are now turned out every month, whereas some years ago they were counted only by tens. Under the head of the various engines an attempt has been made to describe the immense number of applications of gas and oil in countries so widely apart as Spain, Siberia, Korea, and Peru.

Electric Lighting.—The competition of electricity with town gas as a means of illumination threatened the prosperity of the gas companies some years ago. Since, however, motive power is required to generate electricity, and is conveniently obtained by driving the engines and dynamos with lighting gas, this method of utilising the output of gas has been adopted by several companies. The advantages of thus producing electricity have long been realised. As it is usually required only during a certain number of hours in the twenty-four, the production may be intermittent, and the engines stopped for a time without incurring any cost, as with steam. Or the gas may be utilised for other purposes

during the day, as is often done in country houses, where it furnishes the motive power for pumping water, sawing, threshing, and other agricultural operations, and after dark the engines drive the dynamos. Although a means is thus found of utilising gas, this method is not as economical as where the engines are driven by cheap or power gas, such as Dowson, Lencauchez, Mond, &c., and for all larger gas-engine plants the latter system has been almost universally adopted. The great development of gas producers has given a fresh impetus to gas engines for generating electricity. At Munster, where electricity for the town is supplied by four 200 H.P. Deutz gas engines, the demand regulates the supply. If much gas coke is required, more gas is produced, and used to drive the engines; if less is wanted, the coke is burnt under generators, and the engine driven with producer gas.

Another new feature is the introduction of suction gas producers, which give the same marked economy of combustible as the pressure gas producers, as compared with dynamos driven by steam engines, while the complication of a boiler and holder is eliminated. All the principal makers in England and abroad build gas engines for electric lighting, in which governing by delicately-graduated admission is adopted, and the engine made to respond to the smallest variations in the load.

The electric light station driven by town gas, set up at Dessau in 1886, was probably one of the first; such plants are now very widely distributed. At Rheims electricity for lighting the town, &c., is provided by five Niel engines, two of 50 H.P., two of 80 H.P., and one of 45 H.P., driven by town gas. A test was made by Professor Witz on an electric lighting plant at Roubaix, where the electricity is generated by two Tangye single-cylinder engines, of 28 and 36 I.H.P. respectively. Engines for this kind of work were at first connected by belting to the dynamos, but the latter are now directly coupled to the crank shaft, and of late years the engines have even been coupled direct to alternators driven in parallel. The subject is, however, much too large to be dismissed in a few sentences, and a separate treatise would be required to do justice to the immense development of gas engines for generating electricity. The various references to it under the head of the different types will show that gas motors of almost all sizes and kinds, driven with town or power gas, or in a few instances with blast-furnace gases, now drive dynamos to furnish electricity for lighting towns, factories, mills, public buildings, private houses, &c., both in Europe and America. A few typical examples of the most modern applications are all that can here be noticed.

Of Crossley engines there are four, each of 160 H.P., at Tunis, six of 40 H.P. at Puteaux, and two of 100 H.P. at Cannes, all worked with Pierson gas. The number driven with Dowson gas is very large; an

important installation is at Leicester, where six Crossley engines develop a total of 340 H.P. At the Ryde Electricity Works (see p. 102) there are two Tangye three-cylinder vertical engines, each of 200 B.H.P., coupled direct to the dynamos. At the electric station at Walthamstow four 100 H.P. Westinghouse engines are now working, and three more are in hand, bringing up the total to 1,650 H.P. Westinghouse engines giving about 1,200 H.P. furnish electric light at Smallfields, and there are numerous smaller installations, ranging from 900 H.P. to 16 H.P., all worked with Dowson gas. A total of 600 H.P. is developed by Dowson suction gas producers.

Coming to foreign engines, many important electric works in Germany are provided with Deutz engines driven with lighting gas; a notable example is at Fürth, where electricity is generated by two 200 H.P. Deutz engines. More than 500 electric stations in Germany and elsewhere are worked with Deutz engines and producer gas. Of these the chief are the Bâle Works with four two-cylinder motors, three of which develop 300 H.P., and one 350 H.P., all directly coupled; and the electrical station at Münster, served by four 200 H.P. two-cylinder Deutz engines. Another interesting plant is at Rade in Schleswig-Holstein, where electricity is provided by three 125 H.P. Deutz engines, worked with coke-oven gas. Besides many four-cycle engines driving dynamos, MM. Koerting have made, or have in hand, two-cycle engines developing 15,000 H.P. driven with blast-furnace gases, nearly 5,000 H.P. with producer gas, and 600 H.P. with coke-oven gas, to supply electricity for lighting and power. For these purposes, suction gas producers are much used abroad. Blast-furnace engines develop such large powers that they are only incidentally utilised for electric lighting, and subserve also many other uses, for which electricity in large works is required. (See various notices to this effect in Chapter xii.) MM. Borsig have made Oechelhaueser engines to drive dynamos developing 4,500 H.P., several of which are worked with Mond gas. According to Mr. Humphrey nearly four-fifths of all the Oechelhaueser engines made are built with this object. The first Diesel engine for electric lighting was supplied in 1903 to the town of Aichach, where there are now two of 96 H.P., driven by paraffin distilled from German brown coal. Each engine drives, by belting, a dynamo making 600 revolutions per minute. At Eschweiler, near Alsdorf, electricity is generated by four Nuremberg engines (Augsburg Maschinen-Fabrik and Nuremberg Maschinen-Bau Gesellschaft), developing a total of over 3,000 H.P., and driven with coke-oven gas of about 336 B.T.U. per cubic foot. Mention has already been made of the large Nuremberg plant at Madrid, worked with Mond gas. Five Nuremberg engines, directly coupled, with a total of 1,600 H.P., provide electric light

at Scheveningen, and one of 350 H.P. at Pisa, all driven with power gas. The Schweizerische Maschinen-Fabrik, Winterthur, have furnished forty-two engines, developing 1,350 H.P. In France there are many plants worked with Niel, Letombe, and Charon engines (see a typical example of Charon motors at p. 145). A smaller type is the Duplex, of which eleven engines, driven with petrol or alcohol, are applied to electric lighting.

Waterworks.—The application of gas engines on a large scale to waterworks has been already noticed. In England there are many water pumping stations worked by engines driven with Dowson gas. Of these two are 20 H.P. Crossley engines at the County Asylum, Gloucester. At Godalming Waterworks there are two 18 H.P., at Ross (Hereford) a 30 H.P., and at Teignmouth two 16 H.P. Crossley engines, all driven by Dowson gas. The Uxbridge pumping station, worked by Atkinson engines, has been mentioned, and there is another plant at Kenilworth. Other applications are at Wellington, Stevenage, and Marlborough, in all of which Crossley engines are used. There are many stations in England where gas engines are used for pumping sewerage. Messrs Crossley have put up several large sewerage-pumping gas engines for the London County Council. Messrs. Tangye have erected many pumping engines for waterworks, sewerage, and drainage, both for small and large powers, and especially a plant of several 120 H.P. engines at the Sunderland Docks, with pumps each discharging 2,600 tons of water per hour. Mills are also driven by gas engines. At Laval in France power for the waterworks is generated by a 60 B.H.P. Simplex engine, driven by Lencauchez gas. Duplex engines have also been utilised for pumps, and fifteen driven with petrol or alcohol are now at work. But it is in Germany that the system has been most widely applied, and the water supply in small towns much improved.

Engines for pumping water may be divided into four classes, according to their motive power, whether driven by lighting gas, power gas, petroleum, or by benzine, volatile oil, or alcohol (on the Continent). In compactness, economy, absence of a chimney or boiler, and little attention required, they all possess great advantages over steam. Another recommendation is, that if the water pumps are worked by engines using town gas, not only are the gas companies benefited, but the output is equalised, more water and less gas being required in summer, while in winter the proportions are reversed. Taking a mean of several towns in Germany, it has been found that in summer from 14 to 30 per cent. of the total output of gas is required for the engines driving the waterworks, and in winter only from 1 to 2 per cent.

The first waterworks in Germany driven by gas engines were those of Düren, in 1885, and other towns have not been slow to follow. The power was transmitted to the pumps through wheels, but pulleys and

OTTO GAS AND OIL ENGINES USED IN GERMAN AND OTHER WATERWORKS.

Town and Date.	Particulars of Engine. Nominal or B.H.P.	Kind of Gas or Oil.	Water Raised.		Revolutions per Minute.		Size of Pumps.	
			Gallons per Hour each Engine.	Height. Feet.	Engine.	Pumps.	Diam. Inches.	Stroke. Inches.
Düren, 1884,	Two engines, 40 H.P.	Lighting gas	27,720	180	140	30	$10\frac{1}{4}$	30
Coblenz,	Three ,, 40 ,,	,, ,,	26,400	190	140	25	$10\frac{1}{4}$	31·5
Fürth,	Two ,, 40 ,,	,, ,,	33,000	148	130	30	11·0	20·5
Carlsruhe, 1888,	Two ,, 50 ,,	,, ,,	46,000	154	140	28	13·1	31·5
Leer,	Two ,, 10 ,,	,, ,,	7,000	197	180	72	5·1	11·8
Treuen,	Two ,, 12 ,,	,, ,,	5,500	287	180	75	4·5	11·8
Göttingen, 1892,	One ,, 10 ,,	,, ,,	6,620	150	180	75	4·0	11·8
	One ,, 12 ,,		12,450				5·5	11·8
Meissen,	Two ,, 50 ,,	,, ,,	22,000	305	150	75	6·2	15·7
Constance, 1894,	One ,, 23 ,,	,, ,,	31,800	82	160	75	3·8	11·8
Wolfenbüttel, 1894,	Two ,, 25 ,,	,, ,,	22,100	148	170	75	7·3	11·8
Munster, 1888-90,	Two ,, 30 ,,	Producer ,,	25,000	177	140	30	9·8	27
Basel (Bâle), 1895,	One ,, 210 B.H.P. / 170 ,,	Lighting ,, / Producer ,,	79,560	308	140	60	10·2	27·5
Rothenburg,	Two ,, 10 ,,	Benzine	4,000	295	180	70	4·3	11·8
Hohenstein,	One ,, 7 H.P.	Petroleum	5,570	170	200	75	5·0	11·8
Since 1900.								
Kupferdreh,	One ,, 100 ,,	Producer gas	...	...	...	...	...	...
Posen,	Two ,, 100 ,,	,, ,,	...	...	...	...	...	...
Godesberg,	Two ,, 60 ,,	,, ,,	...	...	...	...	...	...
Bromberg,	Three ,, 50 ,,	,, ,,	...	...	...	...	...	...

KOERTING GAS AND OIL ENGINES FOR DRIVING PUMPS IN WATERWORKS (GERMANY).

Town.	Date.	Number of Engines.	Size.	Gas or Oil Used.	Water Raised.	
					Cubic Feet Per Hour.	Height Feet.
Verden,	1892	Two	12 H.P.	Lighting Gas	5,522	173
Sagan,	1893	Two	16 ,,	,, ,,	4,046	164
Hameln,	1895	Two	25 ,,	,, ,,	2,260	223
Buckeberg,	1895	One	10 ,,	,, ,,	762	219
Mulhausen (Thuringia),	1895	One	15 ,,	,, ,,	...	153
Kirchheim,	1897	One	6 ,,	,, ,,	1,059	134
Jena,	...	Two	25 ,,	,, ,,	2,648	221
Zoological Gardens (Hanover),	1897	One	30 ,,	Power Gas	2,118	...
Emden,	1896	Two	...	Benzine	1,764	262
Moringen,	1898	One	...	,,	847	98
Grüneberg,	1895	One	8 ,,	,,	1,016	239
Prüm,	1897	One	4 ,,	,,	1,060	182
Pforta,	1895	One	8 ,,	,,	783	209
Bacharach,	1898	One	7½ ,,	,,	670	164

belting are now generally used, and among the latest developments are the quick-running Riedler pumps, coupled direct to the gas engine. In engines driven by generator or power gas, in towns already supplied with lighting gas, as at Basle, gas coke can be utilised; but it is usual also to connect the engines to the gas mains, that they may be started quickly and easily in case of emergency. In smaller towns, where there is no gas, and not much power is required, petroleum or benzine may be employed to drive the pumping engines. With benzine, as with lighting gas, the engine can be started without previous heating.

Of the two foregoing tables, the first, compiled from data in the *Zeitschrift des Vereines deutscher Ingénieure*, March 16, 1895, gives particulars of some of the principal towns in Germany where the waterworks are driven by Otto gas or oil engines, chiefly by belting or ropes. At the present time (1905) the Gas-Motoren Fabrik Deutz have supplied engines to 260 towns and private waterworks, developing a total of 5,000 H.P. The second Table shows some of the towns in which the water is pumped by Koerting gas or benzine engines. The Schweizerische Maschinen-Fabrik have also four engines for the waterworks at Cairo, giving 140 H.P.

The actual consumption in these engines varies considerably with the height to which the water is raised, &c., but the following is about the maximum and minimum :—

1 lb. gas coke will raise from 4,750 to 7,000 lbs. water to a height of 131 feet.

1 cubic foot lighting gas will raise from 310 to 560 lbs. water to a height of 131 feet.

1 lb. oil or benzine will raise from 7,500 to 12,000 lbs. water to a height of 131 feet.

A special application of gas engines to pump oil through many miles of pipes is at Baku on the Caspian, where a large plant is served by Diesel engines (see p. 470). A drawing of one of the pumping stations will be found in the *Zeitschrift des Vereines deutscher Ingénieure*, 1903, No. 38. The pipe line has been laid to convey oil from Baku to Batoum, a distance of 620 miles, the gradients of the line being steep. There are thirteen stations, delivering 1,000,000 tons of petroleum per year, at Batoum, at a pressure of 50 atmospheres = 700 lbs. per square inch, and five of these stations are provided with Diesel engines. One has three 100 H.P. engines; the other four stations have four two-cylinder engines, each developing 150 to 180 H.P. Each engine is coupled to two Riedler differential pumps. A small pump circulates the cooling water in a contrary direction to the petroleum, the pressure of which creates a current of air, thus reducing the temperature of the water.

Tramways Driven by Gas.—The use of gas for street traction is

an application of motive power which appears capable of extension, though it does not seem yet to have been widely employed. The Lührig system is that most generally adopted. The gas is drawn from a main, compressed by a stationary gas engine to the required pressure, and the reservoirs of the trams are charged with it. One advantage of this method of providing motive power is that in most towns where tramways are used, a gas main is always available. Tramcars driven by compressed gas are also self-contained, and carry with them a store of motive power sufficient to last for a considerable time. Steam tramways are rather noisy, and the exhaust is sometimes objectionable; electrically propelled cars, although so much in favour at present, require overhead wires, or other methods of conveying electricity, while the greater expense of horse-drawn cars has long been recognised. The relative cost, as given by Mr. Corbett Woodall some years ago, was one penny per mile for tramways driven with compressed gas, twopence per mile with electricity, and fivepence per mile for horse traction.

In gas tramcars from 6 to 10 reservoirs for the compressed gas are required, containing from 44 to 88 cubic feet. They are placed beneath the floor of the carriages, and charged with a supply sufficient to run the cars about 8 miles. About 8 per cent. of the total quantity of gas consumed is used to drive the fixed engine for compressing it. An 8 H.P. engine will compress 2,100 cubic feet of gas per hour to a pressure of about 8 atmospheres.

There are two systems of propelling cars by compressed gas, that of Guilliéron and Amrein at Neuchâtel in Switzerland, and the better known Lührig system, adopted in Germany. At Neuchâtel the tramway is worked by an 8 H.P. gas engine, and the receivers carry sufficient gas for the double journey, 3 miles each way. The consumption is 34 cubic feet of gas per car mile. The Lührig gas traction system invented by the late Herr Lührig in 1893, was first adopted at Dresden in March, 1894. The principle is that of connecting the engine to the carriage by means of friction coupling, controlled by the driver. The carriage can be stopped by clutches, without stopping the engine. Professor Schöttler gives a description, with diagrams, of the Lührig system of transmission in the *Zeitschrift des Vereines deutscher Ingénieure*, August 24, 1895. There are three shafts, each connected to the motor shaft by levers, and carrying wheels of different diameters. By shifting the levers, one or other shaft and set of wheels are thrown in or out of gear. The motor is a double-cylinder 9 H.P. Otto engine, with electric ignition. There are three speeds, corresponding to almost total suppression of gas; a partial supply, with a speed of the car of 4½ miles per hour; and a full supply, with a speed of 9 miles per hour. The gas is carried in three cylindrical reservoirs, and a fourth holds the cooling

water; the latter is placed on the roof of the carriage, beneath an upper tier of seats. The water descends by gravity to the cylinder jackets, and after cooling them circulates through tubes exposed to a current of air produced by the onward motion of the car. In all gas or oil engines used for propelling cars, portable engines, road carriages, &c., the arrangements for cooling the water form an important feature.

The gas tramway at Dresden proving successful, another plant worked by a two-cylinder 10 H.P. Otto engine was laid down at Dessau in November, 1894. The line is nearly 3 miles long, and the supply of compressed gas is sufficient for a distance of 8 miles; the consumption is about 29·8 cubic feet of gas per car mile. As the town was already lit by electricity, it was originally intended to have an electric tramcar, but as this involved an additional station, it was decided to utilise the gas from the mains. The average speed of the Dessau tramway is about 7½ miles an hour; a careful study of it was made by Sir Alexander Kennedy. A tramway worked by gas was also laid down in July, 1896, between Blackpool and St. Anne's, a distance of 7½ miles, and worked satisfactorily for some time. The power was supplied by a 15 B.H.P. engine.

A later application of gas and oil engines to locomotion is to drive the dynamos for generating electricity, now so greatly used in street tramcar propulsion. There are many instances of this abroad; in England it does not seem so much in favour at present. The Zurich-Oerlikon electric tramways are worked by three 125 H.P. Deutz engines, directly coupled to the dynamos, and driven by producer gas. For the tramways at Cassel (France), the electricity is generated by five 26 H.P. Crossley engines, driven with Pierson gas. A Diesel 100 H.P. engine for electric traction, coupled direct to the dynamo, is said to be working in London. The Schweizerische Maschinen-Fabrik, Winterthur, have supplied a 100 H.P. single-cylinder and a 200 H.P. two-cylinder engine driven with poor gas, to work the tramways at Saint-Ouen (Seine). Trials made in 1902 gave the consumption at 0·87 lb. of anthracite per B.H.P. hour. This firm have also built engines of 440 H.P. at Berne, and of 220 H.P. at Bienne, all worked with lighting gas, to drive the electric tramways in those towns. Probably the most important installation is a group of Diesel engines, developing nearly 2,000 H.P., to work the street tramcars in Kieff (Russia).

Boats for Rivers and Lakes.—During the last ten years there has been a great development of internal combustion engines, as applied to marine propulsion. One of the first vessels thus worked was a cargo boat, the "Idéale" of 300 tons burden, which plied for some time between Havre and Paris. It was driven by a 40 H.P. two-cylinder

Simplex engine, the motive power being supplied by gas previously compressed to 100 atmospheres. The vertical pistons were set at an angle of 90° and acted downwards upon the shaft of a reversible screw, on the M'Glasson system. The compressed gas was stored on the bridge of the vessel in tubes, similar to those used for compressed oxygen in England. From thence it was drawn as required, the pressure reduced to the proper strength for the charge, and the gas mixed with air in a separate chamber.

It is, however, with oil engines that the greatest progress in this direction has been realised. The **Capitaine** oil launch was perhaps the earliest in the field, and is now well known, and extensively used. It was introduced into England, and a launch was tested at Chester in 1891. By means of a handle attached to the gearing, the motion of the boat could be reversed or suspended; in the more modern types a reversible propeller is also sometimes used. This launch was 35 feet long by 6 feet 10 inches wide, and carried 50 passengers. The 6½ H.P. engine made 240 revolutions per minute; the boat ran at 8½ knots per hour. In these little oil launches the motor is not stopped with the boat, but simply disconnected. There are usually two vertical cylinders in the centre of the vessel, with the oil reservoir under the bow, and a connection to the boat screw shaft at the stern. The exhaust gases sometimes escape through a chimney in the middle of the boat, sometimes they are carried along the side, and discharged at the stern. The pressure of air in the oil receiver is maintained by a pump worked from the motor, which sends the oil to a smaller reservoir, also under pressure, connected to the cylinder. Another pump supplies water for the cooling jacket. The Capitaine launches are driven by ordinary petroleum. As now built in large numbers by Messrs. Tolch, of Fulham, these marine engines are made vertical only, in sizes from 1 to 5 B.H.P. single cylinder, up to 30 B.H.P. double cylinder, and 60 B.H.P. with four cylinders, and run at 360 to 240 revolutions per minute. Nearly six hundred have been supplied to various governments and private firms, and a large number are at work at Hamburg, on the Rhine, the Thames, in Africa on the Niger and the Congo, in Madagascar, Palestine, and elsewhere. They are fitted to launches, yachts, lifeboats, barges, pinnaces, &c.

The **Daimler** petroleum launch is an application of the Daimler engine to propel a boat, with special apparatus to transmit the power to the screw. It has been largely and successfully applied for driving small boats. The author inspected one of these little petroleum launches on the Thames several years ago. It ran quietly, with no smoke and little smell, was easily steered, the direction reversed, or the boat stopped at a moment's notice. The speed varied

from 8 to 11 miles an hour. Hundreds of Daimler launches, driven with light petroleum of 0·68 or 0·70 density, are at work in Germany and elsewhere. A vertical four-cylinder 10 H.P. Daimler boat engine was exhibited at Chicago. The motor always works in the same direction, and is connected to the screw shaft by a disc and friction coupling. If all three are in connection the boat goes forward; by turning a handle two side friction discs are brought into play, and the motion reversed. Instead of this gear some boats carry propellers with reversible blades. When the engine is running at its normal speed of 480 revolutions per minute, the boat attains a speed of 15 miles per hour, and the consumption of oil is about 0·64 lb. per mile. The engine, oil tanks, and exhaust are arranged in the same way as in the Capitaine launches, and one man is sufficient to steer and drive the motor.

The earliest application of oil engines to river work was by Messrs. **Priestman**, and they still make these vertical motors, in sizes from 2 B.H.P. upwards. Hitherto, in these and all other engines applied to boats, the vertical type only has been adopted. The Priestman have usually two or four cylinders, and are used for barges and other purposes, where the safe working of the engine in unskilled hands is the first consideration. They are employed on rivers and lakes in Europe and elsewhere. Transmission is effected by a reversible propeller, the movement of the boat being altered, while the engines run continuously in the same direction. The reversal of the propeller blades is obtained by a hand wheel near the steering gear, the direction of rotation of the screw shaft not being affected, as in other engines.

Most of the principal makers in England and abroad now build a marine type of engine. Messrs. Tangye have introduced a small two-cycle vertical motor to work with petrol, benzoline, or carburetted alcohol. With the exception of the Capitaine and Priestman, marine engines worked with heavy oil are somewhat rare. For an account of the American Otto marine engine applied to the Holland submarine torpedo boat, see p. 430. A description of the Campbell oil engine for hauling barges will be found at p. 412. Messrs. **Vosper**, of Portsmouth, have constructed the Roots engine for river work, and make oil launches in sizes from 1 H.P. upwards, with one, two, or four cylinders. One advantage of having several cylinders is that, by bringing one or more into use as required, the power can be accurately adjusted; for intermittent work, as with barges going through locks, &c., this is a desirable arrangement.

The **Griffin** oil engine, described at p. 403, has been largely and successfully applied to marine work. As a launch engine the "Duplex-" Griffin is made vertical, with two cylinders and pistons; the latter are rigidly connected to a crosshead, and work downwards through a single

connecting-rod on to the crank. The method of reversing the action of the boat is ingenious. There are two screw propellers with right- and left-handed pitch respectively. The forward propeller is mounted on a hollow shaft, the backward propeller on a smaller solid shaft enclosed within the larger. Either shaft and propeller can be connected to the crank shaft, or both can be thrown off, if necessary, by means of a double-friction clutch worked by a hand lever. The engine runs always in the same direction, it is its action on the propeller that is varied, and the movement of the boat reversed in a moment by the motion of the lever. For starting the engine the small flywheel is disconnected by a friction clutch from the crank shaft, and rapidly rotated by a hand wheel and chain. As soon as it has acquired sufficient energy the crank shaft is thrown on, and the engine starts. Engines of this "Duplex" type are made in sizes from 5 to 100 H.P. In the 35 H.P. "hydro-oil" marine engine fitted to a barge at Liverpool, and described at p. 404, the two cylinders are 11 inches diameter by 14 inches stroke, and the speed is 240 revolutions per minute.

Among foreign marine engines an interesting novelty is a **Deutz** 20 H.P. motor, driven by a suction gas producer, and fitted to a canal boat, 128 feet long, of 280 tons burden. A 50 H.P. Deutz petroleum engine has also been applied to a three-masted schooner. As a reserve of power such engines are frequently used. Of the **Gnome** engine a marine type is also made, in which the changes of direction are effected by friction coupling. These engines are fitted both to decked and undecked vessels, The **Diesel** is also built as a marine motor by Sautter and Harlé, of Paris (see p. 470). There are two pistons moving in opposite directions in one long horizontal cylinder, the crank shaft being in the centre, at the inner dead point, and the valves disposed above it. The compression space is immediately over the crank chamber. The main shaft carries four cranks set at an angle of 180°. The object of this arrangement is to obtain a good turning moment and balance of the reciprocating parts; the strain falls, not on the longitudinal, but on the transverse axis of the ship.

In the **Forest** motor the rotation of the engine itself is reversed, and not that of the screw shaft. These ingenious vertical engines carry a valve shaft and a double set of cams for reversing the motion (see p. 437). A few appear to be made in France, but they are practically unknown in other countries. For an account of the Duplex engines as applied to trawlers and fishing boats see p. 441. For this class of work marine oil engines have been very largely used during the past few years.

Portable Engines.—Oil and alcohol motors for agricultural work are now extensively employed. They have entered into active competition with steam, and all the important firms in England, America, and on the

Continent have taken up their manufacture. The annual agricultural shows held at various large manufacturing centres in Great Britain have also greatly aided in the development, and given an impetus to the construction of portable oil engines. Gas engines are, of course, useless in the country, where the chief demand for this class of motor arises, because there are no mains or gas works at hand. Steam engines must have a boiler, and a provision of water and fuel. Portable oil motors are easily handled, compact, light, and require only two small tanks, one for oil, one to hold water for the cooling jackets; the latter is now sometimes replaced by air cooling. They are easily and quickly started and stopped, and oil may be procured anywhere. The chief drawbacks to their use, their smell and rather fragile construction, have been practically overcome. For portable engines petroleum is preferred in England to lighter oils, because a certain quantity must be carried, but benzine and alcohol are much used abroad. Motors igniting the charge spontaneously, without an external flame, have also a considerable advantage in open windy places over those carrying an exposed light. Special attention is now paid to economy in the supply of cooling water, which is often very limited, and various arrangements with this object have been described under the head of the different engines. If abundance of water is available, the method generally adopted, especially abroad, is to allow the jacket water to evaporate, and renew it as required; but if the supply is insufficient, it is generally circulated over and over again, and cooled by a current of air created by the engine itself, by radiating ribs, or by passing it through an arrangement of vertical baffle plates.

Oil engines are now much used in mines, and on light railways for transport of all kinds, to work travelling cranes, circular saws, and for numerous other purposes. For these applications the engines are mostly horizontal, and can often be adapted, with slight modifications, to work with any kind of gas or oil, alcohol or acetylene. The Deutz firm alone have in six years built more than a hundred oil and spirit locomotives, with a total of 1,000 H.P. Locomotives for mines are made in sizes up to 24 H.P., for light railways up to 60 H.P., the consumption being about 0·7 lb. petroleum or alcohol. Another new development is the sectional oil engine of Messrs. Fielding & Platt, which can be taken to pieces, and built up again on arrival at its destination. Mention must also be made of the military traction oil engine, recently constructed by Messrs. Hornsby (see p. 399). The conditions laid down by the War Office for this kind of engine were so stringent that the Hornsby firm alone were able to comply with them. The chief requirements were that the tractor should run 40 miles without a fresh supply of fuel, and although required to haul a load of 25 tons, should not itself exceed 13 tons in weight. It was successfully subjected to a test of 500 miles run over soft and hilly

roads. It was also taken through 2 feet of water, and set to climb a hill with a gradient of 1 in 6, hauling 12½ tons load. This engine was vertical, with two cylinders one above the other. The water for the jackets was circulated by a rotary pump, through a cooler beneath the engine. At p. 199 will be found an account of the extensive use of engines driven with Loomis gas, to generate electricity for various power purposes in mining, smelting, and forging operations, &c., in California and the United States.

Berlin Trials.—Three important series of trials of portable and stationary oil engines, with special reference to agricultural work, were made in 1894, in Germany at Berlin by Professors Schöttler and Hartmann, in France at Meaux by M. Ringelmann, and in England at Cambridge. The reports of these trials give full particulars of the different engines submitted to the tests. In the Berlin trials twenty-seven engines, portable and stationary, of 2 to 12 H.P., were exhibited by fifteen different firms. All the most important German makers were represented, and one English firm. The engines were repeatedly and severely tested with American or Russian oil of 0·80 to 0·82 density, and the consumption of oil per B.H.P. per hour determined at half, full, and maximum power. The time required to get the engine into full work, the number of explosions missed, the extent to which the horse-power could be increased beyond the normal, to meet unforeseen demands, supervision required from the attendants, steadiness of external flame, and cleaning after a prolonged run, were all noted. Particular attention was paid to the build of the engine, to avoid vibration with the wheels; shielding of the lamp from sudden extinction by wind; method of cooling the cylinder, quantity of cooling water required, and efficiency of the jacket. It was found that, unless the latter was in satisfactory working order, the cylinder either became too much cooled and the heat efficiency was reduced, or too little heat was carried off and the engine worked badly. Details of most of these careful tests will be found in Table 9.

Meaux Trials.—Eight portable engines took part in the Meaux trials—two English, three French, two German, and one Swiss motor. The same Russian oil of 0·82 density was used throughout, and the power was limited to 4 H.P. It was found that the general classification of the engines by the judges, with respect to their economy and excellence of construction, followed the heat efficiency per B.H.P., or the ratio of heat turned into actual work to total heat supplied. The experiments were on the same lines as those at Berlin, and the results in the original report are plotted in curves and shown in diagrams. The quantity of air required for combustion was determined from the number of explosions, the volume of the piston, and the consumption

of oil. When the actual volume of air was in excess of this theoretical quantity, the explosions were weak; when it fell below it, imperfect combustion was the result. Variations in the speed were also noted. Details of these excellent trials are given in Table 9.

Cambridge Trials.—The trials of oil engines at Cambridge were in connection with the Royal Agricultural Society, and fifteen engines were entered for competition. These included most of the best English makers, but no foreign motors were exhibited. In these trials, as at Berlin, the primary object was to determine how far oil engines could be relied on for farm work when handled by unskilled labourers, and simplicity of design, strength, durability, stability, and freedom from internal fouling, were specially tested. The engines were first run on the brake for three days of ten hours, then with full load, without any intermediate cleaning. None exhibited any traces of soot or dirt, though in all the oil was vaporised in a different way. Russian oil was used, of 0·82 specific gravity, and the power was fixed at from 4 to 16 B.H.P. The Hornsby and the Crossley were commended for economy, efficiency, and steadiness. The portable engines shown by these firms were also the best, with the lowest consumption of oil per B.H.P. hour. Most of the engines exhibited were good, but the examiners, both English and foreign, in the three series of trials at Berlin, Meaux, and Cambridge, were of opinion that in all there was room for improvement. For detailed results see Table of Tests, No. 9.

Second Berlin Trials.—Another careful series of trials of portable engines, perhaps more interesting to English students from a theoretical than a practical point of view, was carried out at Berlin in 1902 by Professors Hartmann, Meyer, and others, on eight German engines driven with alcohol. The construction of most of the motors tested has already been described. The time required to start each engine was specially determined, and it was found that the full load could be thrown on in from 1½ to 6½ minutes after starting with benzine. With oil engines the consumption of oil at equal loads greatly depends on the method of admitting it; these alcohol engines were therefore tested in the same way, by acting on the pitch of the screw regulating the admission of the combustible. According to Professor Meyer there is for every engine a certain consumption of oil or alcohol corresponding to the highest efficiency, and this consumption should be known. The power of the engines tested varied from 6 H.P. to 16 H.P., and their consumption of alcohol of 11,000 B.T.U. per lb. ranged from 0·85 lb. to 1·34 lbs. per B.H.P. hour. All the engines tested were governed on the hit-and-miss system, and ran at full load with a mean of 2 per cent. miss-fires. The extent to which the consumption increased at half load and running light was determined. The degree of compression each engine could bear

was also studied, since upon it depended the efficient utilisation of the combustible, and it was found that, the higher the compression, the more susceptible was the engine to variations in the load. With alcohol, as with oil, mere pulverisation is not sufficient to form a properly explosive charge; it must also be vaporised by the application of heat, and the extent to which this previous heating of the charge affected the compression was considered in each case. With mixtures slightly or not at all previously heated, a much higher compression is possible than when the charge is already at a high temperature on admission. Another point is that if alcohol or oil be highly heated it expands, and thus a smaller quantity per stroke is admitted to the cylinder. The heat efficiency of the engines tested was very high, about 32 per cent. with the Deutz, and 33 per cent. with the Marienfeld engine. Professor Meyer's exhaustive report of these trials should be studied (see *Zeitschrift des Vereines deutscher Ingénieure*, 1903).

Road Motor Carriages.—The latest devopment of oil engines, and one which has excited more public interest than any other, is their use to propel road carriages and bicycles. The law prohibiting the use on roads in England of mechanical carriages driven at more than 4 miles an hour was repealed in November, 1896, and this gave a great impulse to their manufacture.

The subject of mechanically-driven carriages has now, however, become far too large to be done justice to in this book, and requires a volume to itself. Tens of thousands of these little vehicles are in use in France, England, Germany, and elsewhere. A great many exhibitions have been held, which have served to familiarise the public with their use, and to reveal the defects which should be corrected. In several of these competitive trials the author acted as judge. Table 10 gives a summary of some of the English tests on carriages for passengers and goods, both by the Royal Agricultural Society and by the Automobile Club, at most of which the author was present.

The **Daimler** motor carriage is made in Germany, and in France by MM. Panhard and Levasseur, and Peugeot Frères. The engine has two cylinders inclined at an angle of about 15° to the crank shaft, and is similar in type to the petroleum motor already described. The gearing, as in boats, is by pulleys and friction coupling, connecting to a shaft which actuates the rear wheels of the carriage. The engine runs at a speed of 600 to 1,000 revolutions per minute, and is disconnected from the driving shaft during a short stoppage. The cooling water is contained in a small tank under the seat, and is sometimes circulated through the framework of the carriage. In some engines there is no water jacket, but the cylinder is ribbed externally, to afford a large air cooling surface. There are two brakes, a hand and a foot. The driving

shaft has a slide and wheels, which work on three other wheels on a shaft above, commanding three different speeds. The direction of the carriage is changed by a conical wheel on the upper shaft, acting on two loose wheels. Between them is a sleeve with teeth, which produces a forward or back motion, according to the wheel with which it engages. This transverse shaft carries a pinion, acting on the axles of the two hind wheels.

In the Daimler motor car, as generally made in England, several speeds are available, and changes of speed are obtained by the action of spur wheels. See Table 10 for consumption of oil, speed on the road, &c.

The **Roots** is another engine worked with ordinary petroleum, which is now made in sizes from 5 to 12 H.P., almost exclusively to drive motor cars. Many other makers construct engines driven chiefly with light oil or petrol, for use with motor carriages, and the types are very varied.

PART III.

AIR ENGINES.

CHAPTER XXV.

CONTENTS.—Theory—Cayley-Buckett—Stirling's First Engine—Stirling's Second Engine—Robinson—Later Type—Ericsson—Wenham—Bailey—Jahn—Rider—Jenkin's Regenerative Engine—Bénier—Genty.

Theory.—In dealing with oil engines no mention has been made of the theory of heat motors, and of their theoretical and actual heat efficiencies, &c., because in these respects oil and gas engines are based on the same principles. The effects of an explosion of coal gas with air, or oil vapour with air, when mixed in the cylinder of an engine, are more or less similar, as also the data, from which the heat efficiencies are calculated. When we consider hot air engines, the conditions are different. There is no explosion, and no great rise or fall of temperature. A certain quantity of heat is applied to air, which expands and drives a piston, doing work. No boiler is needed, nor is any cost incurred for gas or oil from a tank, the air as working agent being taken from the surrounding atmosphere. There is no risk of explosion from inflammable gas or oil vapour. No change of physical state in the working agent takes place, and therefore all the heat generated and imparted to the air can, in theory, be utilised in work. The two main sources of waste of heat in gas engines are the cooling water jacket and the exhaust. In a hot air motor there is no jacket (unless as a refrigerator), and therefore less heat should be dissipated, and more available for work. From these considerations, therefore, it seems as though a hot air engine must be not only better in theory, but more economical in practice, than other forms of heat motors.

Such, however, is not the case. Practically, hot air engines do not give results as satisfactory as might have been expected. Though the first engine of this type was designed in 1807, comparatively few have since been made, and their construction has not been much developed, except for special purposes. The reason for this neglect may probably be found in their low actual efficiency—that is, the amount of heat they turn into work. In theory the whole of the heat furnished to the air

being utilised in expansion, a high rate of efficiency should be obtained. Practically, expansion cannot be continued to the pressure of the atmosphere, and, therefore, some heat remains in the air, and is wasted at exhaust. The theoretical heat efficiency of an engine depends upon the range of temperature—that is, its highest and lowest working temperatures. But if heat be added to the air up to 900° F., and if the temperature of exhaust is 600° F., only the difference, or 300°, will be spent in expansion, and heat equivalent to 600° will be wasted. As in gas motors, the difficulty consists in utilising the expansive force of the agent, air. Since expansion cannot be unlimited, only a certain proportion of the heat imparted can be turned to account as work. If it were possible by expansion to reduce the air in a hot air engine to the temperature it had before entering the cylinder, an efficiency of about 59 per cent. might, according to Professor Jenkin, be realised; the actual heat efficiency, or percentage of work done to total heat received in these engines, is only from 7 to 10 per cent. The Stirling engine worked between the temperatures 343° C. and 65° C. The theoretical efficiency, according to the formula at p. 277, was

$$\frac{T_1 - T_0}{T_1}, \text{ or } \frac{343^\circ - 65^\circ}{343^\circ + 273^\circ \text{ (abs.)}} = \frac{278}{616 \text{ (abs.)}} = 45 \text{ per cent.}$$

The actual efficiency (see p. 502) was 7 per cent.

Difficulties of Hot Air Engines.—To increase the efficiency and check the source of waste in these engines—that is, the high temperature of the exhaust—the only method would appear to be to increase the ratio of expansion, and this can only be done by raising the initial compression of the air. But this does not produce any real advantage, because the pressure which is expended must be deducted from the pressure exerted upon the piston. To compress the air before it is admitted to the cylinder requires a certain amount of negative work, or work done *on* the working agent. The further compression is carried the greater the proportion of negative work, and the lower the proportion of positive work, or work done *by* the air. If the air be compressed to 100 lbs., 65 per cent. of the work would be required in theory to obtain this compression. It is also difficult to prevent leakages where high pressures of air are used, and to keep all the parts of the engine perfectly air-tight, while to obtain an efficient working pressure it is necessary to use a large body of air. Air is a very bad conductor and does not absorb heat readily, and it expands in comparison with its bulk much more slowly than steam. In the Ericsson air engine, the pressure was only 3 lbs. per square inch.

Hot air engines are therefore bulky, and seldom suitable to replace

steam or gas. Their special advantages are—1. Ease in working. 2. Absolute safety. For these reasons they are sometimes employed for driving fog signals on lightships, lighthouses, and in other isolated places, where these advantages outweigh the defects. They have also been used for domestic and other purposes, namely, pumping, sawing, printing, driving tools, for small powers, &c. As the price of gas and oil is reduced, and explosive motors are more cheaply driven, air engines are likely to be more and more discarded in their favour.

Cayley-Buckett.—The earliest air or caloric engine was introduced by Sir George Cayley in 1807, and patented by him in 1837. The original design has been adopted by Mr. Buckett, and practically the same engine was made by the Caloric Engine Company. Fig. 157 gives

Fig. 157.—Buckett Air Engine—Single Cylinder.

a modified view of the Cayley-Buckett Caloric engine. It consists of two distinct parts, like the boiler and motor cylinder of a steam engine. A is the working cylinder containing the piston P, B is the furnace in which the air is heated. Above the motor cylinder is a second pump cylinder J, into which air is admitted through the valve M, and compressed by the action of the piston P_1. The two pistons are connected to each other, and the up expansion stroke of the one forms the compression stroke of the other. The air, after being compressed in J, passes through the valve I and down the passage *d* in the direction of the arrows, till it reaches a cylindrical valve *c*, directly

controlled by the governor G above it. Here the current of compressed air is divided. Part of it passes down the passage *g*, between the firebrick lining W of the furnace and the outer casing, and is admitted through holes at the bottom of the grate to the furnace B, where it stimulates combustion. The rest passes through the upper part of the valve, enters above the furnace at *f*, as shown by the arrows, and mingling with the products of combustion, prevents the escape of unburnt carbon. From here the hot air and products are carried off through the passage *h* into the motor cylinder, where by expansion they drive up the piston P. They are admitted through a lift valve V which, as well as the exhaust valve E on the opposite side of the cylinder, is driven by valve-rods, levers, and cams from the crank shaft K. Coal is fed into the furnace through the hopper H and the door D. During this time the valve R closes the top, to maintain the air pressure in the furnace during stoking. By opening the cock at *r* a portion of the hot air enters the hopper, and the pressure is equalised. As soon as D is closed, R is lowered into the furnace by the chain S. Combustion is regulated by passing more air, either under the furnace at *g*, or over it at *f*. If the speed is too great, the governor acts upon the cylindrical valve, and checks combustion by forcing the greater part of the air to mingle with the products of combustion from the fire. The Cayley-Buckett engine has no regenerator, but by an ingenious arrangement the cold air, after being compressed in J, is led round the valve V, admitting the hot air and gases to the motor cylinder. Thus the valve is kept cool, and the fresh charge of air heated on its way to the furnace. The air being exhausted at each stroke, a closed cycle cannot be obtained.

Trials.—In a trial on a 12 H.P. nom. double-cylinder vertical Buckett engine, the difficulties of this class of motor were well shown. The gross I.H.P. was 41·24 and the pump I.H.P. 21·04. Thus more than half the power was employed in negative work, leaving only 20·2 H.P. for working the engine. The B.H.P. was 14·39, and mechanical efficiency only 71 per cent. The mean pressure on the pistons was 18·5 lbs., on the pumps 16·78 lbs. per square inch. The coke consumption was 2·54 lbs. per B.H.P. per hour, and only about 8 per cent. of the total heat supplied was turned into work. The engine ran at 61 revolutions per minute, the diameter of the working cylinders was 24 inches, of the pumps 18 inches, stroke 16 inches. Fig. 158 gives an indicator

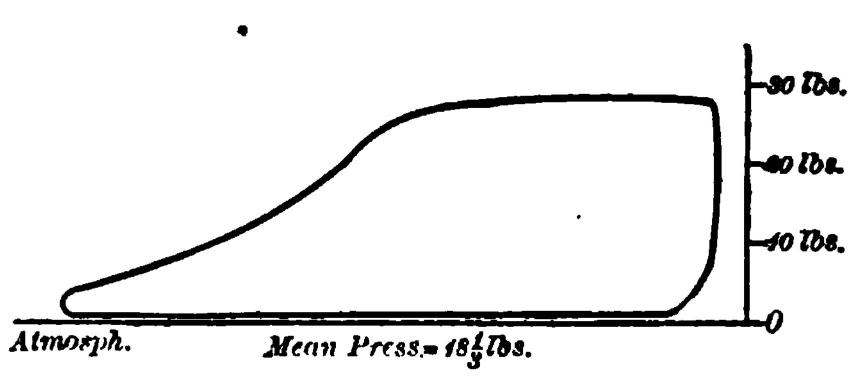

Fig. 158.—Buckett Air Engine—Indicator Diagram.

diagram of the engine. A motor similar to the Cayley Buckett was described with illustrations in *Engineering* in 1887.

Stirling.—The first application of the principle of the regenerator to heat engines is due to Robert Stirling, a Scotch minister, who, with his brother James Stirling, an engineer, took out several patents for heat motors, the first dating from 1827. Stirling's double merits as an inventor have not until lately received sufficient recognition from scientific men, perhaps because he was, like many other pioneers, in advance of his time. He first endeavoured to carry into practice the principle of a perfect heat engine (Carnot's cycle), and he also designed the regenerator. In a perfect heat motor the same quantity of heat is imparted to and withdrawn from the working agent, so that at the close of the cycle it returns to its original state, and the series of operations may be reversed. Robert Stirling obtained this perfect theoretical cycle by means of the second great improvement he introduced, the use of a regenerator, in which the heat of the working agent (air) is stored as it leaves the cylinder, and refunded afterwards, as it returns to the furnace. Many scientific men are of opinion that the proper development of the principle of the regenerator affords the chief possibility of improving the working cycle of heat motors, but it does not seem of late years to have been successfully applied to internal combustion engines. The regenerator has been ingeniously called a "filter," because both the hot and cold charge are "filtered," or passed through it at their highest and lowest temperatures. It is intended to diminish as far as possible the waste of heat at exhaust. It acts by arresting and storing the heat remaining in the working fluid after expansion, instead of allowing it to escape to the atmosphere, and gives back this heat to the next charge in its passage to the cylinder. The result is obtained in this case by making the hot gases pass through thin metal plates, wire gauze or other heat absorbing substances, to which they give up their heat, and carrying the cold charge back through the same metal to receive heat from it.

Stirling's First Engine.—Stirling took out two patents for hot air engines working with a regenerator. In the first, dated 1827, he proposed to have a motor cylinder and piston, an air pump, and two hot air vessels. The vertical motor cylinder and air pump were attached to a horizontal beam driving the crank; an eccentric and parallel motion worked the pistons of the air vessels through a balance beam. Each of these vessels or cylinders contained a plunger piston composed of thin metal plates forming the regenerator. A furnace being lighted beneath the cylinders, air, compressed by the air pump into a receiver in the base, was admitted at the bottom to start the engine, and to supply the loss by leakage. By its expansion it drove up the motor

piston, and in its passage through the plungers gave some of its heat to the regenerator. The cylinder covers of the air vessels were kept cold, and the air on reaching the top became immediately chilled. The hot air cylinders communicated, the one with the bottom, the other with the top of the motor piston. As the air decreased in temperature its pressure fell, and both the motor piston and the piston of one of the air vessels descended. At the same time the air in the other cylinder, being heated, expanded, and by its pressure drove down the piston of the motor cylinder. Each time the cold air descended, it passed through the regenerator, and became heated afresh.

Fig. 159.—First Stirling Engine. About 1830.

In Fig. 159 a modified view of this engine is shown. A is the motor cylinder and P the piston, B the air or displacer cylinder, and D a plunger piston working in it, F the space where the air is heated by the fire. The plunger or displacer D is filled with brick-dust, or other non-combustible material. The circular regenerator R is round D, and consists of metal plates about $\frac{1}{40}$ inch in thickness and $\frac{1}{50}$ inch apart. E is the refrigerator at the top of cylinder B, and is formed of coils of copper tubes through which cold water circulates; the hot air from the displacer cylinder acts on the motor piston. The cycle of the engine is as follows:—When the displacer piston is at the top of cylinder B, all

the air is below it in F, heated by contact with the fire. As the air expands, its pressure is transmitted to the working cylinder, and it drives up the piston P. The displacer piston is now driven down and forces the air below, through the regenerator, into the vessel and refrigerator at the top of cylinder B. While the displacer is in its lowest position, the motor piston comes down. The air in B, which has already transferred the greater part of its heat to the regenerator, is further compressed, and passes round the refrigerator pipes E, where it is cooled, the heat from the furnace being shut out by the non-conducting material in D. By the energy of motion left in the flywheel, D is lifted, and, beginning to rise, forces down the cold air above it through the regenerator, where heat is added to it before it reaches the furnace. The motor piston P is driven up by its expansion, and the cycle recommences.

Stirling's Second Engine.—In Stirling's second engine, introduced in 1840, patent No. 8,652, the regenerator and refrigerator are placed on one side of the cylinder. Fig. 160 shows the arrangement, the parts are lettered as before. C is the displacer cylinder, D the plunger, F the space below it, A the passage leading to the motor cylinder. E is the refrigerator cooled by water, I the passage to the regenerator. The action of the engine is the same as before. There are one motor and two hot air cylinders. The air is delivered into the cylinder by a small pump at a pressure of 150 lbs. per square inch, and passes through the regenerator from one hot air cylinder to the other, driving the motor piston up and down in its passage. There is no exhaust, the same air being used continuously, and a closed cycle is thus obtained. This engine presents in a compact form the main principles of Stirling's invention, and illustrates better than any other type of motor the construction of a perfect heat engine. Here we have the source of heat (the furnace), the source of cooling (the refrigerator),

Fig. 160.—Second Stirling Engine. 1840.

and between the two the regenerator, which abstracts heat as the air passes to the refrigerator, and refunds it as it returns to the source of heat. One of Carnot's chief propositions is here put in practice. Heat is imparted to the working agent at its highest temperature, and withdrawn at its lowest. In both cases its temperature, previous to this addition and subtraction of heat, is raised and lowered by the regenerator. Theoretically a perfect reversible heat engine was the result, but in practice it did not work well, and only about 7 per cent. of the total heat produced was utilised as motive power. A Stirling engine was used to drive machinery for three years at the Dundee Foundry. It indicated 40 H.P., had a cylinder diameter of 16 inches, and 4 feet stroke, and required about 2½ lbs. coal per H.P. per hour.

Robinson.—A small engine embodying Stirling's principles was brought out by Robinson, and made by Messrs. Pearce & Co., of Manchester. It is very compact, with one vertical single-acting cylinder containing two pistons. The lower is the displacer and regenerator, and is filled with wire gauze, acting in the same way as in the Stirling engine. The section of the cylinder in which the displacer moves to and fro is lined with firebrick, to retain the heat. In the upper part of the same cylinder is the working piston, and here the cylinder is surrounded by a water jacket, to serve as a refrigerator. The two pistons work through connecting-rods on two different cranks at right angles to each other; the crank of the displacer is in advance of the motor crank, and the displacer-rod works through a stuffing-box in the motor piston. Instead of a grate and coal, in which much heat is dissipated, the temperature of the working agent is raised by a Bunsen burner, fed with air heated by passing through a jacket outside the chimney carrying off the products of combustion. When the displacer piston is at the top of its stroke, all the air below it is heated by the burner, expands, and drives up the motor piston. As the displacer comes down, it forces the air to pass through the regenerator into the space above, between the two pistons. Some of its heat has already been carried off by the regenerator, and it is here further cooled by contact with the cold water jacket of the refrigerator. The pressure falls, and the working piston descends. The displacer now rises, and the cold air is forced down through the regenerator. In its passage it regains the heat it had parted with, before it reaches the hot plate above the Bunsen burner, where it is heated afresh, and the cycle repeated. In this engine the only cost is the supply of gas to the burner, which is about ½d. an hour for a 1-man power engine. The air pressure is low, and no pump is used to supply loss by leakage; the power produced is very small for the size of the engine. The largest size made is a 2-man power, running at 270 revolu-

tions per minute; the cylinder diameter is 8 inches, length of stroke 5 inches. A drawing of this engine is given in Professor Jenkin's valuable paper on "Gas and Caloric Engines" (*Proceedings of the Institution of Civil Engineers*, 1883), from which many details of this and other hot air engines have been taken.

A type of this engine has been introduced by Messrs. Norris & Henty, of Manchester, and is shown at Fig. 161. The principle of the

Fig. 161.—Robinson Air Engine.

motor is the same, but the position of the two pistons is different, the working cylinder being horizontal, the displacer vertical, and the axes of the two in the same plane. B is the motor cylinder with piston, the displacer A has a hollow perforated piston I filled with wire gauze. C is the furnace in which any fuel can be used, but coke is preferable; for very small powers a gas flame, as in the earlier engine, is most convenient. There is no exhaust chimney, the air at D being used over and over again. The motor piston works through the connecting-rod H and crank pin G on to the crank shaft E, while two links on the same

pin give motion to a lever F, which works the displacer piston. The latter is one-fourth in advance of the motor piston. There is said to be no loss of air by leakage, because it is so rapidly cooled by the cold surrounding walls that the pressure falls below atmosphere during the out stroke, and any escaping air is drawn in again by the resulting vacuum. An engine of $\frac{5}{8}$ H.P. is said to work at a cost of 1d. per hour per H.P.

One chief reason for the low pressures and small amount of work obtained from the Stirling, and its failure as a practical engine, was that the air was not brought into direct contact with the heat of the furnace. In the displacer cylinder, a thin metal plate intervened between the fire and the hot air, the bottom of which was soon burnt by the great heat. There is no exhaust in engines of this type, the air being used over and over again, and the pump only replacing loss by leakage, but this advantage is counter-balanced by the difficulty of heating the air. In the Cayley-Buckett engine it is passed through the furnace and, mingled with the products of combustion, drives up the motor piston, and is exhausted after expansion, as in an ordinary heat engine.

Ericsson.—The latter type of motor is best exemplified in the celebrated engine produced by Ericsson in 1826. As an engineer, Ericsson was a genius not inferior to Robert Stirling. During the first half of the nineteenth century he introduced numerous mechanical inventions, and is said to have designed the first screw propeller. In his engine hot air was used in conjunction with steam. It was drawn into a furnace below a steam boiler, and after producing combustion of the fuel, and evaporating the water, it was carried off, together with the products of combustion, and drove up the piston of an air cylinder by its expansion. On its way it passed through a regenerator. In an alternative engine described in the same patent, it was proposed to mix the products of combustion and the hot air with the steam, and admit them alternately at either end of the motor cylinder, as in an ordinary double-acting engine. After expansion, they were exhausted into the atmosphere. Thus the heat was applied directly to the air. Of course it was impossible to use the air over again, since it was required fresh at every stroke, to support combustion.

These two engines, the Stirling and the Ericsson, form two distinct classes, into one or the other of which all hot air engines can be divided. In the first, the air does not come in contact with the flame, but is heated by conduction and by the regenerator, and is not discharged at each stroke. In the second, it is applied directly to feed the flame, and, mingled with the products of combustion, produces motive power by expansion, after which it is exhausted. In both engines the practical heat efficiency, as compared with the theoretical,

is very low. Admirable as types, they cannot, for the amount of heat they turn into work, be ranked with gas, oil, or steam engines. The chief reasons for this deficient utilisation of heat have been already explained. A large quantity of heat must be added to the air, before its temperature is high enough to produce a proper working pressure. This necessitates large cylinders, that a sufficient volume of air may be heated, and their bulk, weight, and friction are serious drawbacks to the extended use of heat motors of this type. In a Stirling 37 H.P. engine, the maximum temperature was only 650° F., and the weight 1 ton per I.H.P. The consumption of coal per effective H.P. is also very large, especially in engines of the Ericsson type. The 600 H.P. engine originally made by Ericsson was said to consume 6½ lbs. coal per H.P. per hour, the heating surface of the regenerator was 4,900 square feet. In the Ericsson engine tested by Professor Norton, the I.H.P. was 321, and consumption of anthracite 1·8 lbs. per I.H.P. per hour, but there were four motor cylinders, each nearly 14 feet in diameter.

Wenham.—The Wenham engine, introduced about 1873, is in some respects similar to the Buckett. The motor is of the Ericsson type, and the air is heated by forcing it through a furnace lined with firebrick, after which it passes to the vertical water-jacketed motor cylinder, driving up the piston by expansion. The distinctive feature of the engine is that the upper surface of the motor piston is used as an air pump. Air is admitted into the top of the cylinder through an automatic lift valve, when the piston is in its lowest position, and the pressure has consequently fallen. As the piston rises, forced up by the expansion of the heated air from below, the pressure closes the valve, and as soon as the air is compressed to 15 lbs., it forces open another lift valve, and passes to the furnace at the side. In the passage through which it is led off is a valve, connected to the centrifugal governor. Here the current of compressed air is separated, part passing over and part beneath the fire grate, to stimulate combustion. The governor regulates the proportions of the two, and thus the rate of combustion, and the pressure of the air delivered to the motor cylinder. Ordinary coal is burnt as fuel. The hot air, after passing upwards, is led off, mingled with the products of combustion, and admitted to the bottom of the motor cylinder through a lift valve, worked by a cam on the main shaft. A similar cam operates a second lift valve for the exhaust. The admission and discharge ports are both at the bottom of the cylinder. The engine is single-acting, the expansion of the hot air drives up the piston, it descends by the motion of the flywheel and by the pressure of the air stored above it, and drives out the burnt products. There are two piston-rods, both working on to the same crank shaft. The consumption is said to be as much as 8 lbs. of coal per

H.P. per hour, which is probably the reason why these engines have been little used. A description with drawings will be found in *Proc. Inst. Mech. Engs.* (London, 1873).

Bailey.—The Bailey engine, shown at Fig. 162, is constructed on the Stirling principle. The products of combustion pass from the furnace to the displacer and power cylinder, where they mingle with and heat the air, driving the piston. The cylinder is horizontal, but in most respects, and especially in the arrangement of the regenerator, the Bailey resembles the vertical Robinson engine. There is one long cylinder, A_1, the crank end of which, closed by the piston, is surrounded by the water jacket, and acts as a refrigerator. The other end serves as the heater and regenerator. This cylinder contains two pistons—P the motor, working on to the crank by a connecting-rod *c* and series of levers, and P_1 the long displacer, the connecting-rod of which passes through the motor piston, and works on to a separate crank at right

Fig. 162.—Bailey Air Engine.

angles to the main crank. The displacer P_1 does not fit closely into the cylinder A_1, but a small passage is left between them, shown at D. This piston is used merely to cause the air to travel backwards and forwards in the cylinder; all the work, including that of driving the displacer, is done by the motor piston. At H is a steel casing enclosing the inner end of the cylinder; F is the furnace. The hot gases and products of combustion pass upwards from the furnace over the fire bridge, in the direction of the arrows, into the space G round H, and the burnt products are carried off through the flue C. The air enclosed in the space L becomes highly heated, and drives out the displacer. As it reaches the narrow opening D, it is chilled by the water jacket, and before it has passed into L_1, on the other side of the displacer piston P_1, it has parted with all its heat. As the air cools its pressure is reduced, the working piston and displacer make their return stroke, and

the cold air is drawn back into the space L, to be reheated first by the steel casing, then by the furnace gases. Thus the heat is added when the temperature of the air has already been raised by the hot end of the cylinder, and withdrawn by the refrigerator after it has been cooled by expansion.

The Bailey engine is said to be based on the designs of MM. Lehmann & Laubereau, but it is really an English engine, strictly modelled on the Stirling type, though the idea of a regenerator is not much developed. There is no exhaust for the hot air, which is used continuously, and the loss by leakage is replaced from time to time through a small valve, when the pressure falls below atmosphere. The absence of valves is an advantage in this class of engine, because the great heat necessary to obtain a working pressure soon wears them out. As the air is introduced direct from the surrounding atmosphere, and no compression pump is used, the maximum pressures are very low. The following details of a trial from Professor Jenkin's paper on "Gas and Caloric Engines" gives the working of a Bailey hot air engine:—The speed was 106 revolutions per minute, and the engine indicated 2·37 H.P.; the mechanical efficiency was 55 per cent., the brake H.P. being 1·31. The stroke was $6\frac{7}{8}$ inches, diameter of cylinder $14\frac{5}{8}$ inches. The highest pressure obtained was 14·7 lbs. per square inch above atmosphere, and the temperature at this pressure was 823° C. The consumption of coal was said to be under 10 lbs. per hour. Fig. 163 gives an indicator diagram taken during this trial. The engine worked easily and required scarcely any attendance.

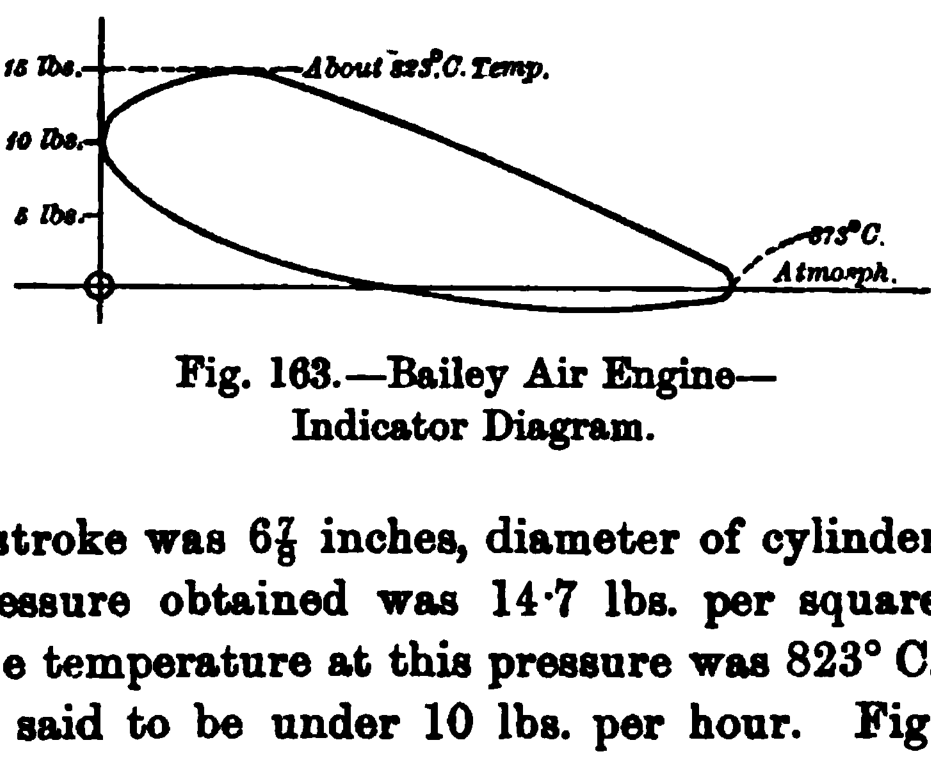

Fig. 163.—Bailey Air Engine—Indicator Diagram.

These figures show that to obtain a pressure of only one atmosphere, a relatively high consumption of coal and high temperature are necessary. These are partly owing to the transmission of the heat through metal to the air. But the difficulty is not removed by passing the air directly over the fire, as in the Ericsson engine, and driving the piston by the expansion of the hot furnace gases. Since the air must be discharged at every stroke, fresh air is continually introduced, and much of the heat obtained is wasted at exhaust. It has also been found that the air, in its passage through the furnace, becomes charged with grit and unburnt carbon, which score the valves and passages, and cause friction and wear of the working parts.

Jahn.—A vertical engine on a similar principle (Hofmann's system) made by Jahn & Co., Boitsfort, Belgium, was exhibited at Antwerp in

1894. This motor has also two pistons, a displacer below and a motor above, working vertically in the same cylinder. The latter is divided into three parts by layers of isolating material, and the heat from the lower part, where the air is heated by a furnace, cannot pass into the upper, which is kept cool by a water jacket. The rod of the displacer piston passes through the centre of the hollow motor piston-rod, and both work on to the same crank. The air heated by the furnace below the displacer passes upwards, and drives up the motor piston; when cooled by the water jacket, it is again forced down by the displacer, to be heated afresh by the furnace, and the cycle recommences. The crank shaft carries a governor which, if the normal speed is exceeded, allows part of the hot air to escape, or prevents fresh air passing to the furnace. The water in the jacket is circulated by a pump. Drawings and a description of this engine will be found in *Zeitschrift des Vereines deutscher Ingénieure*, June 29, 1895.

Rider.—The Rider was an ingenious little air engine brought out in America, and made in this country by Messrs. Hayward & Tyler. It is a compact and handy single-acting motor, useful for domestic purposes, and to pump water. It presents almost all the features of the Stirling type, the regenerator, the furnace below heating the air through metallic walls, with no exhaust or other valves. There are two vertical cylinders, as shown at Fig. 164, one is heated by the furnace beneath, the other is kept cool by a water jacket. The same air is used continuously, and is passed alternately from one cylinder to the other. Unlike the Stirling, however, the motor piston is placed in the hot cylinder of this engine, and it is here that the power is developed. A is the working, and B the second cylinder, which acts as compressor, displacer, and refrigerator. Each has a plunger piston of unequal stroke and diameter, P and P_1, working through connecting-rods, J and J_1, on two cranks on the main shaft, carrying the flywheel. The cranks are set nearly at right angles. The cylinders are open at the top, closed only by the pistons. W is the water jacket surrounding the compression cylinder B; the piston of cylinder A ends in a concave cylindrical part F, over the furnace, round which the hot air circulates. Between the cylinders is a passage containing the regenerator R, formed of a number of very thin iron plates. As the air passes through this regenerator it either takes in or gives out heat, according to the direction in which it is going, whether from the hot to the cold cylinder, or back again. The fire at G greatly heats the air in the space above it at F, and forces up the piston P by expansion. Meanwhile the displacer P_1 is at the bottom of its stroke, it then begins to rise slowly, drawing over into cylinder B, by its suction, part of the hot air in A. Until this air is completely cooled, its pressure helps the ascent of piston P_1. When the motor piston P has reached the top of its

stroke, the other plunger is more than half-way through, and as P descends, it displaces all the hot air in cylinder A, and drives it into the cold cylinder B, through the passage and regenerator R, where a large portion of its heat is deposited. The air, already reduced in temperature, is further cooled by the water jacket W, its pressure falls, and the plunger piston P_1 descends, compressing the cold air below it. It is

Fig. 164.—Rider Air Engine.

during this period—the last part of the downstroke of P_1—that the fly-wheel does work, there being no air in the hot cylinder to act by expansion, but the power exerted during this compression stroke is not nearly as great as the power previously developed by the expansion stroke in A. By the time the plunger P_1 has reached the end of its stroke, the motor

piston has begun to rise, and the air is again displaced and transferred from the cold to the hot cylinder. As it passes back, it absorbs heat from the regenerator, and more heat from the concave part F in the motor piston, which forces it against the hot walls of A. When it reaches the furnace the cycle recommences.

The chief peculiarity of the Rider engine is that the motive power is not only generated but exerted in the hot cylinder, above the furnace. This is not a desirable arrangement. In all his various designs, Stirling was careful to keep the motor cylinder cool, and even in the modifications of his engine where all the operations take place in one cylinder, that part of it containing the working piston is cooled by a water jacket. The speed in the Rider engine is from 100 to 140 revolutions per minute, and the maximum pressure about 20 lbs. above atmosphere.

Jenkin's Regenerative Engine.—A hot air engine on the Stirling principle, with a regenerator, but in which hot air passes directly over the furnace and, mingled with the products of combustion, drives up the piston, was introduced by Fleeming Jenkin. In the first type of his Fuel Regenerative engine, patented in 1874, coal gas and hot air were used together to form an explosive charge. This vertical engine had a combustion cylinder with displacer piston, a motor cylinder with working piston, and two pumps for compressing the air and gas, all driven from the same crank shaft. The combustion cylinder was lined with firebrick, and had below it a chamber formed by the clearance space, and continually maintained at a white heat by the explosions of compressed gas and hot air taking place in it. The displacer piston contained the regenerator of fine wire gauze, as in the Stirling engine; at the top of this cylinder was the cooling chamber. The air from the air pump was driven into the upper part, and forced downwards through the regenerator by the displacer piston. In the combustion chamber it mingled with the coal gas or petroleum admitted into the cylinder by a second pump, and the compressed air, already heated by its passage through the regenerator, produced the ignition of the charge. The hot gases and products of combustion expanded, and, entering the bottom of the motor cylinder at a high pressure, forced up the piston. The exhaust gases were passed through the regenerator before being allowed to escape into the atmosphere. A drawing of this engine will be found in Professor Robinson's book.

A second regenerator engine, designed by Professor Jenkin and Mr. Jameson, was described, with drawings, in Professor Jenkin's paper already referred to. Here the object was to construct an engine of the Stirling type, but in which the heat was directly transmitted to the motor piston. One cylinder only was used, the upper part containing the refrigerator, and the lower the regenerator, but the clearance space

was too large, and there was consequently great loss of pressure. To work the engine a coke fire was made below the cylinder, and the air as it became heated drove up the pump or displacer. As it expanded, it passed through the regenerator round the circumference of the cylinder. Here heat was withdrawn from it, and it became still further cooled by contact with the refrigerator or water jacket, at the top of the cylinder. The contraction of the cold air caused it to pass downwards again to the fire, and heat was restored from the regenerator, and from the firebrick lining of the clearance space. This engine did not go beyond the experimental stage.

Bénier.—M. Bénier, whose gas engine is mentioned at p. 152, also brought out a hot air motor. It is a vertical single-acting engine; the

Fig. 165.—Bénier Air Engine. 1886.

piston-rod works through a horizontal beam on to the connecting-rod and crank. Fig. 165 gives an external view. There is one motor piston, with furnace below; the connecting-rod and crank shaft are shown to the left in the drawing. Another rod, by means of a rocking lever, works the horizontal air pump, seen through the opening in the base of the engine. The air pump is single-acting, and sends a current of air at each stroke to the furnace below the cylinder through a slide valve. The valve works between a slide face and cover, and has openings corresponding to ports in the cylinder. It is driven by a cam on the crank shaft actuating a lever, and is held in position by springs. The centrifugal governor inside the central column, worked by a pulley on the crank shaft, acts upon a small crank below the air pump, and closes the air

opening from the pump to the furnace more or less according to the speed. The air is drawn cold into the air pump, and delivered at a pressure of 15 lbs. per square inch into the furnace, where it expands and acts directly upon the piston, as in engines of the Ericsson type. The greater part passes downwards to the grate, but part is ingeniously introduced into a small groove hollowed out in the cylinder. The motor piston is very long, and the lower part is made slightly smaller than the cylinder, and does not exactly fit it. In the space thus formed round the lower end of the working piston, the current of cold air circulates, keeps the piston cool, and prevents the escape of dust or unburnt carbon from the furnace below. The exhaust is on the other side of the cylinder. The products of combustion are discharged through an ordinary lift valve, raised as the motor piston begins to descend, by levers acted on by a cam on the crank shaft. The furnace is fed automatically by means of two hoppers. The proper quantity of small coke for each charge is conveyed from one to the other, and the second hopper, shown to the right in the drawing, discharges its contents into a port in a slide valve, which shoots the coke down into the furnace. This distributing slide valve is driven by wheels from the crank shaft, and holds the grate hermetically sealed during expansion and the ascent of the piston.

The Bénier appears to be one of the simplest and most efficient of hot air motors, and requires no attention beyond cleaning out the grate once a day. For coast fog signals it was tested and approved by the Trinity House Authorities. A complete and careful test on a 4 H.P. nominal engine was made by Professor Slaby at Cologne in December, 1887. The speed of the engine was 117 revolutions per minute. The total indicated work in the motor cylinder was 9·23 H.P., pump 3·38 H.P.; available power only 5·85 H.P. The B.H.P. was 4·03, and mechanical efficiency 69 per cent. The consumption of coke was 3·6 lbs. per B.H.P. and 3·1 lbs. per I.H.P. per hour. Only 6 per cent. of the total heat supplied was transformed into useful work.

Genty.—An air engine of a similar type to the Bénier was brought out by M. Genty, but does not seem to have met with much success. A 17 B.H.P. motor was bought by the French Government to drive the dynamos generating the electric light on the Cap d'Antifer Lighthouse, and to compress air for a syren. The engine has a vertical motor cylinder on one, and an air pump on the other side of a horizontal beam, supported in the centre by a column. The hollow foundation below serves as an air reservoir and regenerator. The valves admitting air to the pump have no springs, but are held closed by a number of small balls, which are said to act quickly and effectually. On leaving the pump the air is forced through the regenerator, a series of tubes round which the exhaust gases circulate, and it is thus heated to a temperature

of about 1,260° F. From thence it passes to the motor cylinder through a throttle valve acted on by one of the two governors; the other governor regulates the pressure in the air reservoir and the intensity of combustion, according to the power required. The furnace is at the bottom of the motor cylinder, and the hot gases from it expand directly beneath the piston, and drive it up. The cylinder is in two parts, the upper being cooled by a water jacket, and the lower perforated to allow free passage to the air. The hollow plunger piston is in three divisions, the lowest fitting into the grate, the centre carrying the piston-rod, and the upper having also a water jacket. The exhaust valve is driven by an eccentric from the crank shaft, and through it the gases pass to the air reservoir. The consumption of this engine is said to be about 2 lbs. of coke per B.H.P. hour.

Experiments on two small air engines, an Ericsson and a Rider, were made in 1896 at the Engineering Laboratory of the Massachusetts Technological Institute, Boston, U.S. Both engines were used for pumping water at the time of the tests. The Rider engine had a cylinder diameter of 6·75 inches by 9·53 inches stroke; in the Ericsson the diameter of the cylinder was 8 inches, stroke 3·9 inches. Particulars will be found in the Table of Tests of Air Engines.

ARRANGED IN ORDER OF MERIT OF HEAT EFFICIENCY,
end of Tables.

t Used U. per h. per B.H.P. T.U.	Heat Effcy. per B.H.P. per cent.	Cycle.	Single or Double Acting.	AUTHORITY, REFERENCE, &c.
170	25·0	4	S	From Prof. Robinson to author.
172·7	24·5	4	S	Report by Witz. Normal load.
176	24·0	4	S	Atkinson, Long Exht. Pipe. *Engineering*, Nov. 30, 1894.
178	24·0	4	S	From Goodman to author. Full power.
193	22·0	4	S	*P.I.C E.*, vol. cxxiv. Long Exht. Pipe.
201	21·2	4	S	Witz, vol. ii., p. 168.
215	19·7	4	S	From Goodman to author. Full power.
226	19·5	2	S	Report of test. Millar, *Effcy. of Gas Engines.*
221	19·2	4	S	Vol. cxxiv., *P.I.C.E.* Clerk Paper, 90 lb. compression.
225	19·0	2	S	*Journ. Soc. Arts*, Feb. 15, 1889.
238	18·0	4	S	Vol. cxxiv, *P.I.C.E.*, see No. 8. Clerk, 60 lbs. compression.
235	18·0	4	S	*Journ. Soc. Arts*, Feb. 15, 1889.
240	17·5	4	S	*Engineer*, July 3, 1892.
245	17·4	4	S	*Donkin Gas Engines*, 2nd edition.
250	17·1	4	S	Goodman to author. Same engine as No. 3 but ½ power.
251	17·0	3	D	Kennedy's Report of Test. Same engine as Nos. 18 and 26.
254	16·7	3	S	Kennedy's Report of Test. Rollason's Patent.
261	16·0	3	D	Jamieson's Report of Test. Same engine as Nos. 16 and 26.
270	15·7	3	S	Kennedy Report, Rollason's Patent. Same engine as No. 17.
272	15·5	3	S	Report, Smith's Test.
289	15·0	4	S	From Goodman to author. Half-power Test. Same engine as No. 7.
280	15·0	4	S	*Engineer*, April 6, 1894.
293	14·5	2	S	Miller on Efficiencies.
291	14·5	2	S	Report of Tests, C. Palace.
309	14·0	4	S	Report of Tests, C. Palace.
297	14·0	3	D	*Journ. Soc. Arts*, Feb. 15, 1889. Same engine as No. 16, less power.
321	13·0	4	S	Report of Test.
327	13·0	2	S	Miller on Efficiencies.
356	12·0	4	S	Report Tests.
412	10·0	2	S	Miller on Efficiencies.
542	8·0	2	S	Miller on Efficiencies.
715	6·0	2	S	Miller on Efficiencies.
16	17	18	19	20—No. of Vertical Columns.

.S.—TABLE No. 2.

ARRANGED IN ORDER OF MERIT OF THERMAL EFFICIENCY,

ɫ CYLINDER 6" BY 12" STROKE. *See Fig. 125, page 330.*

ɫaust Gases. ɫis by Volume. ɫper cent.		Clearance Volume to Total Cylinder Volume. per cent.	Tempt. Jacket Water Out. Deg. F.	Original Test No.	Heat Efficiency per cent. taking	
..	O.				I.H.P.	B.H.P.
	8·6	25 min.	144°	15	21·0 max.	17·0 max.
	9·6	41	145°	7	18·0	14·6
	11·6 max.	25 min.	152°	17	18·0	14·5
	10·8	36	160°	10	17·6	14·2
	7·0	37	134° min.	11	16·4	13·3
	6·4	49	144°	2	16·2	13·1
	7·6	46	148°	5	15·6	12·6
	7·4	49	148°	3	15·5	12·5
	5·2	49	146°	4	15·4	12·4
	5·8	36	149°	9	15·2	12·3
	9·4	37	140°	13	15·0	12·1
	6·6	41	151°	8	14·4	11·6
	10·6	25	141°	14	13·6	11·0
	6·6	25	138°	16	13 4	10·9
	10·0	57 max.	142°	1	12·6	10·4
	0·4 min.	37	168° max.	12	11·7	9·5
	14	15	16	17	18	19

ɫlume air to volume gas from 5·3 to 10·8. Heat efficiency
ɫg Value of Gas from 586 to 635 T. U. per cub. ft.

16 LMPRESSIONS—VIZ., A, 55 LBS. PER SQ. INCH; B, 71 LBS. PER SQ.
HIGHEST AND TWO LOWEST THERMAL EFFICIENCIES FOR EACH

Test an Orde Me	haust Gases. sis by Volume.		Clearance Volume to Total Cylinder Volume. Per cent.	Tempt. Jacket Water Out. Deg. F.	Original Test No.	Heat Efficiency per cent. taking	
	ent. g.	Per cent. O.				I.H.P.	B.H.P.
A	8	8·57	0·57	151	A 4	18·7	15·0
	4	9·70	0·57	140	A 5	18·7	14·2
	1	10·07	0·57	137 min.	A 6	18·3	12·4
	4	11·64	0·57	147	A 8	17·7	12·0
B	0	6·25	0·45	153	B 3	19·4	16·7 max.
	8	9·98	0·45	149	B 7	20·5	15·0
	4	9·19	0·45	142	B 6	20·7	13·8
	5	1·05	0·45	146	B 1	19·0	13·7
C	4	8·12	0·34	144	C 5	20·0	15·8
	4	9·20	0·34	149	C 6	19·9	14·9
	8 .	0·82 min.	0·34	147	C 1	17·7 min.	13·2
	2	12·45	0·34	155 max.	C 8	19·9	11·9 min.
D	3	9·09	0·25	151	D 5	22·7 max.	16·3
	9	7·42	0·25	147	D 4	22·2	16·2
	9 .	12·90 max.	0·25	147	D 10	22·5	14·4
	2	5·32	0·25	144	D 2	19·0	14·2
		14	15	16	17	18	19

t efficiency per B.H.P. from 11·9 to 16·7 per cent.
om 540 to 562 T.U. per cubic foot.

Professor Meyer, arranged in Order of Merit of
... at end of Tables.

Volume Air to Volume Gas.	Per cent. of Clearance Volume to Total Volume.	Heat Effcy. per B.H.P. per cent.	Remarks and Reference.
8·3	23	19·4 max.	3 out of 12 tests, including best and lowest results. All from *Z. V.D.I.*, March, 1899.
9·5 max.	do.	19·2	
8·1	do.	18·5	
...	26	19·4	3 out of 16 tests, including best and lowest tests.
6·8 min.	do.	18·9	
7·5	do.	18·3	
8·4	31	17·7	3 out of 10 tests, including best and lowest tests.
6·7	do.	16·7	
7·3	do.	15·7	
7·0	37	13·6	3 out of 11 tests, including best and lowest tests.
7·1	do.	13·4	
8·1	do.	13·0 min.	
14	15	16	17—No. of Vertical Columns.

TESTS INCHES BY 13 INCHES STROKE. ELECTRIC IGNITION. BY Professor
LIGHTING GAS, nine WITH POWER GAS. TAKING HIGHEST,
lations at end of Tables.

	Pressures (Absolute).		Rise in Temperature of Cooling Water. Degrees F.	Original Test Number.	Heat Efficiency.		Heating Value of Gas (Lower). T.U. per cubic foot.
	ximum Cylinder. . per sq. in.	At end of Compression. Lbs. per sq. in.			I.H.P. Per cent.	B.H.P. Per cent.	
Lighting Gas.	287·0	113·7	37	41	32·7	24·5 max.	585·6
	308·5	113·7	38	29	26·0	18·7	578·8
	300·0	118·7	40	28	24·7	15·2	568·7
	283·0	105·2	40	16	26·1	19·5	573·2
	216·0	105·2	40	18	26·8	18·7	568·7
	173·5	103·8	41	14	26·4	14·7	617·0
	234·6	81·0	37	*57a*	25·8	20·2	590·0
	207·6	102·3	35	*48a*	25·5	16·5	591·1
	149·3	83·6	37	*49b*	24·0	14·6	584·5
Power Gas.	226·0	109·4	39	*40a*	27·3	18·1	123·4
	248·8	109·5	37	*38c*	23·2	16·9	142·2
	172·0	112·3	38	*39c*	23·8	15·0	140·0
	227·5	98·1	40	20	23·2	17·5	136·3
	196·2	101·0	37	*25b*	22·4	15·6	131·0
	156·4	102·3	42	*22b*	22·8	14·2	121·0
	147·8	81·0	38	*54c*	21·6	16·7	127·3
	145·0	82·4	41	*52b*	21·9	13·8	133·5
	130·8	82·4	38	*51a*	21·8	12·1 min.	135·3
	11	12	13	14	15	16	17

1903.

...le Cylinder, Single-Acting. Arranged in Order of ...nd of Tables.

...onsumption, ...ncluding ...ition, per ...our, per		Consumption T. Units per Minute.		Heat Effcy. per I.H.P. Per cent.	Heat Effcy. per B.H.P. Per cent.	Authority and Reference.
...P. ...ft.	B.H.P. Cub. ft.	I.H.P. T.U.	B.H.P. T.U.			
·7	15·4	127·3	143·0	33·3	29·6	*Z.V.D.I.*, vol. xliii.
·2	18·0	117·5	149	36·1	28·4	Do., do.
	16·0	...	158	...	26·7	Witz, vol. iii.
·2	15·5	140	164·5	30·3	25·7	Report by Witz.
	19·2	...	193	...	22·1	Witz, Report Test.
1	20·0	193·2	203	22·0	21·3	Witz, 3rd edition, p. 214.
	21·2	...	210	...	20·3	*Soc. d'Encouragement*, 1890.
0	23·0	212	244	20·0	17·3	Schöttler, 3rd edition, p. 165.
4	32·5	259	297	16·3	14·2	Schöttler, 3rd edition, p. 164.
5	29·1	252	300	16·8	14·0	Miller on Efficiencies. Also Clerk.
0	33·2	266	305	16·0	13·9	Slaby, Report.
	14	15	16	17	18	19—No. of Vertical Columns.

...glish and Foreign, ARRANGED IN ORDER OF MERIT OF ...B.H.P.

Heating Value of Gas per cub. ft.	Heating Value of Fuel per lb.	Gas Used per hour, including Ignition, per		Heat Efficiency.		Reference and Name of Fuel Used, &c.
T.U.	T.U.	I.H.P. c. ft.	B.H.P. c. ft.	Generator per ct.	Engine per B.H.P. per ct.	
113·0	7,657	67·2	77·4	71	29·0	Meyer's *Report.* *German Brown Coal.*
143·8 lower	...	52·0	69·2	...	25·6	Humphrey, *Inst. M.E.*
129·5	...	57·9	81·5	...	24·1	*German Gas Lighting Journal*, 3rd Nov., 1900. 2-cycle double-acting engine.
155·0	12,060	65·7	79·3	81	22·2	From Humphrey. Small coal.
90·13	...	60·1	...	...	21·78	Humphrey, *Inst. M.E.*
144·0 lower	14,200	...	90·0	67	21·5	*Z. V.D.I.*, Dec. 21-28, 1895. Belgium anthracite.
144·0 lower	14,200	...	88·0	61	20·2	Do. do.
152·0 higher	...	...	85·0	...	19·8	French Anzin coal. Report, Delamare.
152·0 higher	...	...	86·0	...	19·5	Witz, 3rd edition, p. 213.
135·0 lower	12,963	...	...	71	19·3	*Z. V.D.I.*, Oct. 24, '96. Gas coke.
131·0	13,500	...	...	...	18·8	Belgian anthracite. *Engineering*, Nov. 15, 1901.
155·0	12,200	71·0	...	81	18·2	*P.I.C.E.*, vol. cxxix. Slack coal.
167·0	...	...	85·0	...	18·2	Witz, 3rd ed., p. 220. Anthracite.
128·0	...	...	...	85	15·0	*Elec. Rev.*, Nov. 5, '97. Coke.
156·0	...	80·0	95·0	...	14·0	Report, Robinson. Anthracite.
...	14,188	...	...	69	13·7	*Journ. Franklin Inst.*, vol. cxxxv.
15	16	17	18	19	20	21—No. of Vert. Cols.

31

[En]glish and Continental. SECOND-CLASS TESTS. NO HEATING [..]4-CYCLE ENGINES. NO HEAT EFFICIENCY CAN BE GIVEN.

No.	[M]echl. Effcy. of [E]ngine per cent.	Fuel per hour per I.H.P. lbs.	Fuel per hour per B.H.P. lbs.	Kind of Fuel Used in Generator.	AUTHORITY, REFERENCE, &C.
1	85	0·74	0·88	Anthracite .	Manchester Assoc. Engineers, March, 1899. 2 engines.
2	...	0·65	0·95	do. . .	Test by makers.
3	...	0·76	1·06	do. . .	*Engineer*, Feb. 12, 1892. 2 cylinders.
4	...	...	1·06	do. . .	Swiss Loco. Co., Winterthur.
5	...	0·77	(1·07)	do. . .	From makers at half load.
6	...	0·85	(1·15)	do. . .	Witz, vol. iii., p. 191.
7	...	...	1·23	do. . .	*P.I.C.E.*, vol. cxii. 4 engines = about 280 H.P.
8	...	...	1·30	French dry coal	Witz, vol. ii., p. 170.
9	69	...	1·34	Anthracite .	Witz, 3rd edition, p. 220.
10	...	1·06	(1·36)	do. . .	*Engineer*, Feb. 12, 1892.
11	77	1·12	1·45	French coal .	Report, Deboutteville.
12	86	1·2	1·4	Bituminous Slack	Report by Messrs. Andrew.
13	...	1·20	(1·50)	Anthracite .	*P.I.C.E.*, vol. cxi. Dowson's paper.
14	81	1·26	1·53	Gas coke . .	Test by makers.
15	53	...	1·58	do. . .	Witz, vol. iii., p. 187.
16	78	1·24	1·60	do. . .	Witz, vol. ii., p. 171.
17	...	...	1·66	do. . .	Witz, vol. iii., p. 189.
18	...	1·30	1·67	Anthracite .	*P.I.C.E.*, vol. cxi. Dowson's paper.
19	...	...	1·70	Coke . . .	Witz, vol. iii., p. 201.
20	...	1·40	(1·75)	Anthracite .	*P.I.C.E.*, vol. lxxiii. Dowson's paper.
21	75	1·40	(1·80)	French coal .	Witz, vol. ii., p. 169.
22	...	...	1·90	Anthracite .	*P.I.C.E.*, vol. cxi. Dowson's paper.
23	74	1·45	1·97	do. .	*P.I.C.E.*, vol. lxxiii. Dowson's paper.
24	...	...	1·97	do. .	*P.I.C.E.*, vol. cxi. Dowson's paper.
25	...	...	3·80	Waste wood, $\frac{2}{3}$ Coal, $\frac{1}{3}$	Witz., vol. iii., p. 213.
[..]s, BUT FEW OTHER DETAILS.					
	85	...	...	Efficiency of Generator 90 per cent.	Heating value of gas 148 T.U. per cubic foot. *Inst. Elec. Engs.*, 1904, part 165.
	...	...	0·81	...	Heating value of gas 148·1 T.U. per cubic foot. Witz Report.
1	12	13	14	15	16—No. of Vertical Columns.

[..]ackets (Col. 14) approximate, and were not given in the Tests.
[..] *at end of Tables.*

INGLE CYLINDER. ARRANGED IN ORDER OF MERIT OF 1·7.

No.		onsumed hour per B.H.P. c. ft.	Heat Used in T.U. per Minute per I.H.P. T.U.	B.H.P. T.U.	Heat Efficiency per I.H.P. p. ct.	B.H.P. p. ct.	Reference and Remarks.
1	"	101·0	134·0	163·0	31·5	26·0	Blowing air, 7¾ lbs. per square inch. *Bull. de la Soc. Ind. Min.*, vol. xiv., p. 1461.
2	D	93·5	139·0	164·0	30·0	25·0	*Z. V.D.I.*, 1899, pp. 448, 483. Full power.
3	D	96·0	141·0	168·0	do.	do.	Do. do. Full power.
4	K	99·0	139·5	175·0	30·0	24·0	*Z. V.D.I.*, 1900, p. 1213. Full power.
5	K	107·0	149·7	200·2	28·3	21·0	Same engine. Less power.
6	D	116·0	153·0	206·0	27·0	20·5	*Z. V.D.I.*, 1899, pp. 448, 483. Half power.
7	"	120·6	182·8	209·6	23·2	20·2	*Revue Univ. des Mines*, vol. lix., p. 273.
8	"	124·0	153·0	209·0	27·7	20·3	Test with brake on same engine as No. 1.
9	"	117·5	183·0	215·4	23·1	20·0	Witz, vol. iii., p. 214.
10	K	126·0	158·0	231·0	27·0	18·3	Same engine as No. 4. Half power.
1		14	15	16	17	18	19—No. of Vert. Cols.

n at End of Tables.

M ONE TO FOUR CYLINDERS. ARRANGED IN
ELECTRIC IGNITION.

No.	...tmed ...ur B.H.P. ...c. ft.	Heat used in T.U. per. Minute per I.H.P. T.U.	B.H.P. T.U.	Heat Efficiency per I.H.P. p. ct.	B.H.P. p. ct.	REFERENCE AND REMARKS.
1	10·0	148·3	166·6	28·6	25·5	*Sibley Journal*, June, 1900. Full load.
2	10·4	155·0	173·3	27·3	24·4	*Sibley Journal*, June, 1900. Full load. Same engine as No. 1.
3	do.	...	do.	...	24·4	Humphrey, *I.M.E.*, 1900. Full load.
4	9·13	144·3	178·8	29·4	23·7	*Sibley Journal*, June, 1901. 4-Cylinders.
5	1·6	165·0	193·3	25·7	22·0	Two-thirds load. Same engine as No. 1.
6	1·7	159·0	202·9	26·8	20·9	*Sibley Journal*, October, 1901. 3-Cylinders.
7	3·69	171·6	221·2	24·7	19·3	Same engine as No. 8 but in better condition.
8	4·7	198·3	245·0	21·7	17·3	*A.S.M.E.*, 1900, vol. 21.
9	8·0	203·3	300·0	20·8	14·4	Do., do. Same engine as No. 8. Less power.
	T, AND MEAN OF NINETEEN EXPERIMENTS.					
10	3·2	109·7	153·4	38·0	27·6	Meyer's Report. Electric Ignition.
11	6·9	140·0	171·7	30·3	24·7	Do. do.
12	7·0	120·3	251·6	35·2	16·8	Do. do.
1	4	15	16	17	18	19—No. of Vertical Cols.

Thermal Efficiency per Brake H.P. Chiefly 4-Cycle.

Oil used per hour including Lamp per I.H.P. lb.	Oil used per hour including Lamp per B.H.P. lb.	Th. Units per Minute per I.H.P. T. U.	Th. Units per Minute per B.H.P. T. U.	Heat Effcy. taking B.H.P. per cent.	Authority, Remarks, &c.
0·33	0·41	107·1	131·2	32·3	*Proc. Inst. Mech. Engs.*, July, 1903.
0·33	0·42	103·2	131·0	32·1	*Z.V.D.I.*, 1903, Nos. 18, 19.
0·32	0·45	182·8	209·6	31·4	*Congrès de Mécanique.*
0·34	0·44	105·0	138·0	30·1	Meyer's report.
0·36	0·46	116·8	147·0	28·8	*Proc. Inst. Mech. Engs.*, July, 1903.
...	0·48	...	148·4	28·5	Report, Taborsky, *The Engineer*, Mar. 21, '02.
0·39	0·49	120·8	154·0	27·5	*Z.V.D.I.*, 1903, Nos. 18, 19.
...	0·50	...	154·0	27·3	From Prof. Meyer.
0·39	0·52	119·0	159·0	26·8	*Z.V.D.I.*, July 24, 1897.
0·40	0·54	122·0	165·0	25·8	Do., do., do.
...	0·537	...	165·0	25·7	From Prof. Meyer.
...	0·55	...	170·0	25·0	Do. do.
...	0·59	...	194·0	21·9	Report, Ringelmann, *P.I.C.E.*, vol. cxxi.
...	0·67	...	201·0	21·0	*Z.V.D.I.*, vol. xliii.
...	0·67	...	221·0	19·2	Report, Ringelmann, *P.I.C.E.*, vol. cxxi.
0·47	0·67	155·6	222·0	19·1	*Engineering*, June 19, 1903.
0·64	0·74	198·0	230·0	18·5	Report High. Agri. Soc. Scotland, 1899.
0·63	0·74	196·0	235·0	18·1	Report, Robinson.
0·61	0·79	190·0	246·0	17·3	Agri. Soc. Scotland, 1899.
0·68	0·80	211·0	249·0	17·1	Do. do.
...	0·76	...	252·0	16·9	Report, Ringelmann, also *P.I.C.E.*, vol. cxxi.
0·73	0·82	226·0	254·0	16·8	*P. R. Agri. Soc.*, 1894.
...	0·83	...	254·0	16·8	*Z.V.D.I.*, Oct. 24, 1896.
...	0·83	...	257·0	16·5	R. Agri. Soc., 1894.
...	0·83	...	257·0	16·5	Do. do.
...	0·82	...	263·0	16·2	Report, Hartmann, L., *P.I.C.E.*, vol. cxxi.
0·71	0·84	222·0	263·0	16·2	Report, Stanfield. Full power.
0·69	0·82	226·0	266·0	16·1	Report, Beaumont.
...	0·83	...	267·0	15·9	Report, Hartmann, Agri. Soc. Germany, 1894.
...	0·84	...	277·0	15·3	Report. Ringelmann.
14	15	16	17	18	19—No. of Vertical Cols.

n. *See Explanations at end of Tables.*

…k of Merit of Thermal Efficiency per Brake H.P.

No.	…g … .	Oil used per Hour, including Lamp, per I.H.P. lb.	Oil used per Hour, including Lamp, per B.H.P. lb.	Th. Units per Minute per I.H.P. T. U.	Th. Units per Minute per B.H.P. T. U.	Heat Effcy. taking B.H.P. per cent.	Authority, Remarks, &c.
31	3	...	0·89	...	292	14·5	*Z. V.D.I.*, Aug. 17, 1895.
32	00	0·86	0·94	272	297	14·3	*P.I.C.E.*, vol. cix.
33	00	...	0·96	...	300	14·2	Agri. Soc. Scotland, 1899.
34	80	...	0·93	...	300	14·2	Report, Hartmann.
35	80	0·77	0·96	240	298	14·2	Same engine as No. 27. Half power.
36	00	0·81	0·97	251	301	14·1	*P. R. Agri. Soc.*, 1894.
37	70	...	0·92	...	304	14·0	Report, Ringelmann.
38	00	0·62	0·98	192	304	14·0	*P. R. Agri. Soc.*, 1894.
39	70	...	0·93	...	307	13·9	Report, Ringelmann.
40	80	...	0·96	...	310	13·7	Report, Hartmann.
41	80	...	0·96	...	310	13·7	Do.
42	80	...	0·96	...	313	13·6	Do.
43	00	...	0·94	...	312	13·6	*Z. V.D.I.*, 1895, p. 616.
44	00	0·93	1·04	288	322	13·2	*P. R. Agri. Soc.*, 1894.
45	80	...	1·00	...	322	13·2	Report, Hartmann.
46	80	...	1·00	...	322	13·2	Do.
47	80	...	1·00	...	327	13·0	Do.
48	80	...	1·00	...	328	12·9	Do.
49	80	...	1·06	...	329	12·9	*P. Agri. Soc. Scotland*, 1899.
50	00	0·75	1·08	233	335	12·7	*P. R. Agri. Soc.*, 1894.
51	00	...	1·10	...	335	12·7	*Z. V.D.I.*, Oct. 24, 1896.
52	80	...	1·05	...	342	12·4	Report, Hartmann.
53	00	0·88	1·10	273	341	12·4	Test by Donkin.
54	00	0·93	1·12	288	346	12·3	*P. R. Agri. Soc.*, 1894.
55	80	...	1·16	...	355	12·0	Report, Hartmann.
56	80	...	1·16	...	353	12·0	Do. (Grob).
57	20	...	1·15	...	358	11·9	*P. Agri. Soc., Scotland*, 1899.
58	80	...	1·10	...	358	11·8	Report, Hartmann.
59	00	0·87	1·19	270	366	11·6	*P. R. Agri. Soc.*, 1894.
60	80	...	1·13	...	366	11·6	Report, Hartmann.
61	80	0·93	1·20	290	372	11·5	*P. Agri. Soc., Scotland*, 1899.
62	80	...	1·21	...	370	11·4	Report, Hartmann (Grob).
63	80	...	1·23	...	375	11·3	Do.
64	00	1·06	1·24	336	393	10·8	*P.I.C.E.*, vol. cix.
65	70	...	1·20	...	396	10·7	Report, Ringelmann.
66	80	...	1·25	...	406	10·5	Report, Hartmann.
67	80	...	1·26	...	410	10·4	Do.
68	80	...	1·30	...	418	10·2	Do.
69	80	...	1·32	...	425	10·0	Do.
70	80	...	1·47	...	477	8·9	Do.
71	00	1·25	1·68	387	521	8·1	*P. R. Agri. Soc.*, 1894.
72	00	0·99	1·72	307	533	7·9	Do.
73	80	...	2·61	...	847	5·0	Report, Hartmann.
74	00	2·1	2·7	695	890	4·8	Clerk, *Gas Eng.*, p. 159.
1		14	15	16	17	18	19—No. of Vertical Columns.

…ons at end of Tables.

b—50 mile run—SOUTHALL TO HIGH WYCOMBE, &c.
ENGLISH AND FOREIGN CARRIAGES.
MAXIMUM SPEED ALLOWED. ROADS FAIR AND DRY.

No.	...st of ...irit ...mile ...per ...on.	Kind of Wheel Tyres.	Kind of Gear.	REMARKS on Road and on Hill; 50 miles run. All Four-wheeled Vehicles. AUTHORITY—Judges' Report, 1899.	Official No.
	...nce.				
1	265	Pneumatic	Strap	Not very good on road. Automobile Association.	32
2	266	do.	Wheels and chain	Very good on hill and road. 5½ H.P. nominal motor.	18
3	285	do.	Strap	Good on road. 12 miles per hour assumed, but went faster.	26
4	365	Solid rubber	Wheels and chain	Very good on road. Less good on hill. 5½ H.P. nom.	19
5	421	do.	do.	Good on road; less good on hill. 12 miles per hour assumed, but went faster.	27
6	435	do.	do.	Good on road; hill not good. 4 nominal H.P. Motor Supply Co.	16
7	495	Pneumatic	Worm wheels	Good on road and on hill.	24
8	523	do.	Wheels and chain	do.	29
9	533	Solid rubber	Belt and chain	Very good on road and on hill. Hewetson.	21
10	561	do.	do.	On road good; hill not good. Hewetson.	22
11	578	Pneumatic	Wheels and belt	Road very good; hill good.	20
12	838	Solid rubber	Belt and chain	Good on hill and road. Automobile Association.	34
13	000	Pneumatic	Wheels and belt	Good on road; hill not good. Automobile Association.	36
14	040	do.	do.	Not good on hill and road.	25
15	100	do.	do.	Good on hill, but not on road. Automobile Association.	35
16	110	do.	Cogs	On hill good; on road fair. Automobile Association.	1
17	200	do.	Belts and chain	Good on hill and road. Automobile Association.	31
18	260	Solid rubber	do.	Many stops on road; hill fair.	23

run. SPIRIT AS ABOVE. SAME REPORT.

19	280	Iron	Wheels	On road good. 10 H.P. nom. Motor Carriage Supply. Lorry.	42
20	450	Solid rubber	Wheels and chain	Post-office Covered Van. Good on road.	44
21	750	Iron	Wheels	Lorry. Good on road. 6 H.P.N. Motor Carriage Co.	43

COKE. COMPOUND STEAM ENGINE. SAME REPORT.

22	50 ...ke	Steel	Gear	Good on road. Steamer. Coke fuel, 10/ per ton.	45
23	50 ...al	do.	do.	Good on road. Steamer. Coal fuel, 20/ per ton.	41

...e run. *Pro* ROYAL AGRICULTURAL SOCIETY, 1898.

24	30	Solid rubber	Chain and gear	Very good on road. Oil spirit, 7½d. per gallon.	..
25	00	Iron	do.	Good on road. 175 lbs. pressure. Coal fuel for boiler, 20/ per ton.	..
26	30	do.	do.	Few stops. 200 lbs. pressure. Oil fuel for boiler, 4½d. per gall.	..
1		15	16	17—No. of Vertical Columns.	18

See Explanations at end of Tables.

n.

No.	chl. cy. er nt.	Fuel used per hour per I.H.P. lbs.	B.H.P. lbs	REFERENCE, &c.
1	1	1·8	2·5	Jenkin, *P.I.C.E.*, 1883.
2	9	3·1	3·6	*Z.V.D.I.*, vol. xxxiii., p. 89.
3	5	4·2	7·6	Jenkin, *P.I.C.E.*, 1883. Sterling type.
4	9	not given	not given	*Techy. Quarterly*, 1896, U. States.
5	5	do.	do.	Compress Cylinder Diam., 6·75 in. Stroke, 8·60 in.
6	3	do.	do.	do.
7	2	do.	do.	do.
8	8	do.	do.	do.
9	3	do.	do.	do.
10	9	do.	do.	do.
11	7	not given	not given	*Techy. Quarterly*, 1898.
12	0	do.	do.	do.
13	9	do.	do.	do.
1	1	13	13	14—No. of Vertical Columns.

APPENDIX A.

EXPLANATIONS OF ELEVEN TABLES OF TESTS OF GAS AND OIL ENGINES.

With Town or Lighting Gas (Chiefly), Tables 1 to 4, with Heat Efficiencies.

Table No. 1.—Gives 32 Tests on different English Engines from	3	to	54	B.H.P.
Table No. 2.—Gives 32 Tests all on same English Engine (Professor Burstall) from	1½	,,	4	,,
Table No. 3.—Gives 12 Tests all on same German Engine (Prof. Meyer) from	5½	,,	10	,,
Table No. 3a.—Gives 18 Tests all on same Deutz Engine (Prof. Meyer) from	5	,,	10·3	,,
Table No. 4.—Gives 11 tests on French and German Engines from	4	,,	65	,,

With Power Gas, Tables 5 and 6, the Former with Heat Efficiencies.

Table No. 5.—Gives 16 First-class Tests on different Engines, English and Foreign, from	7	to	368	B.H.P.
Table No. 6.—Gives 27 Second-class Tests on different Engines, English and Foreign, ...	3	,,	290	,,

With Blast Furnace, Natural, and Coke-Oven Gases, with Heat Efficiencies.

Table No. 7.—10 Tests on different Foreign Engines driven with Blast-furnace Gases, from	21	to	725	,,
Table No. 8.—12 Tests on different Engines driven with Natural and Coke-oven Gas, from . . .	66	,,	606	,,

Oil Engines with Heat Efficiencies.

Table No. 9.—74 Tests on different Engines, English and Foreign, from	2	,,	164	,,

Oil Motors and Passenger Carriages on Roads; also Goods.

Table No. 10.—26 Tests on different Engines, giving lbs. oil used per mile per ton weight. At Richmond by Judges of Automobile Club, London; at Birmingham by Judges of the Royal Agricultural Society; also a few tests on Steam Lorries for comparison.

Table No. 11.—Air Engines, 13 Tests.

Note.—T.U. means always B.T.U. or British Thermal Units.

TABLE 1.—Lighting Gas—TESTS OF English Engines, 1873-1902.

These 32 Tests are chiefly on four-cycle, single-acting motors, and are tabulated in order of merit of heat efficiency per B.H.P. They are nearly all on different motors, although, in a few cases, the same engine was tested at different loads. *Col. 1* gives a No. to each experiment. *Col. 2.* The name of the maker. *Col. 3.* The name of the experimenter, and includes many well-known scientific men. *Col. 4.* Town or Place where the test was made. *Col. 5.* The year of test. *Cols. 6 and 7.* The diameter of cylinder and stroke in inches. *Col. 8.* The mean number of revolutions per minute during the test. *Cols. 9 and 10.* The I.H.P. and the B.H.P.; the latter varies in this table from a minimum of 3·to a maximum of 54. *Col. 11* is the mechanical efficiency per cent., found by dividing the figures given in Col. 10 by those given in Col. 9. For example, in No. 1 test the I.H.P. is 26·4, the B.H.P. 23·0, then 87 per cent. of 26·4 gives 23, and this is called the mechanical efficiency. Approximately, the engine takes 13 per cent. of the power generated to drive itself, and this gives a measure of the friction of all the working parts, which it is important to diminish as much as possible by lubrication or otherwise. *Col. 12* gives the heating value of the gas used on the day of test in British Thermal Units per cubic foot, generally determined in a gas calorimeter at a certain temperature and pressure, but sometimes calculated from the analysis of the gas. It varies from 813 to 561 T.U. in this table. All these values, being English, are stated in what is called the lower heating value of the gas, as explained fully when dealing with this subject. *Cols. 13 and 14* give the cubic feet of gas consumed per hour per I.H.P. and per B.H.P., including ignition. This is obtained by the readings of a reliable gas meter, allowance being made by the experimenter, when necessary, for the temperature and pressure as recorded at the gas meter, so as to correct the values when tested in the calorimeter. *Cols. 15 and 16* show the heat in B.T.U. per minute consumed by the engine, both for the I.H.P. and the B.H.P. This is calculated in the following way, from Cols. 13 and 14. Let us take, as an example, No. 1 test. The cubic feet of gas per hour per B.H.P. was 16·1, this multiplied by the heat in one cubic foot of gas—viz., 630 T.U.—gives the T.U. per hour, and dividing by 60 minutes, we obtain 170 B.T.U. expended per B.H.P. per minute, as in Col. 16. The figures in Col. 15 are calculated in the same way. This useful figure of heat expended per minute per B.H.P. enables us to make comparisons with other heat engines, such as steam or oil. *Col. 17* gives the heat efficiency of each motor per B.H.P. This is the most important column for comparing the different engines, and is here adopted as the *figure of merit*. It is arrived at as follows, taking, as an example, test No. 1:—Col. 16 gives the actual heat expended per minute per B.H.P., in this case 170 T.U. Now, in a theoretically perfect motor, only 42½ T.U. per minute should be expended in heat per B.H.P., instead of 170 T.U. per minute. Dividing 42½ by 170 gives 25 per cent. as the heat efficiency. In other words, this motor expended four times the theoretical quantity of heat. Some may ask how this constant 42½ is arrived at? It is simply 33,000 ft.-lbs. per minute, or one H.P. divided by Joule's equivalent of heat—viz., 778 ft.-lbs. for one T.U. Dividing 33,000 by 778 equals 42·42. All the heat efficiencies for these tests in all the tables have been worked out in the same way.* *Cols. 18 and 19* give the cycle, whether two-, three-, or four-cycle, and also show whether the engine is single- or double-acting. *Col. 20* gives the authority, reference, &c., for each test. The B.H.P. varies in this table from

* All the calculations in the later tables have also been worked out on the basis of

$$\frac{42{\cdot}42}{\text{T.U. per minute per I.H.P. or B.H.P. (respectively)}}$$

about 3 to 54; the mechanical efficiency from 66 to 88 per cent., according to the different motors. When buying an engine it is important to see that it absorbs the minimum power in all its working parts, especially in the piston rings and crank shaft bearings, where the greatest friction generally occurs. Lubrication should be attended to, and most makers guarantee a certain mechanical efficiency. It is, however, much more important that they should guarantee the heat efficiency for a certain sized engine working with a certain gas. The heating value of the gas used in the different towns varies from 561 to 813 T.U. per cubic foot. A simple statement or guarantee that a given engine will consume so many cubic feet of gas per hour per B.H.P. is merely approximate, and means little. The heating value of the gas should always be mentioned. The best figure for any guarantee as to economy between a maker and a purchaser is, however, the heat efficiency per B.H.P. A sliding scale in the shape of a money premium or fine, to vary in proportion to the actual heat efficiency and the guaranteed efficiency, appears just to both parties. This heat efficiency should be determined for a given load and speed and a given gas, from the results of an official test on the engine in question.* The cubic feet of gas per I.H.P. and per B.H.P. vary in the table from 14·5 to a maximum of 30 for modern motors, and in the older tests 40 to 70 cubic feet. The heat efficiency per B.H.P. varies from a maximum of 25 per cent. to a minimum of 6 per cent. for older engines; in modern motors, say, from 25 to 15 per cent., according to different makers, different types, speeds, and sizes of engine, and loads, &c., &c. For this first table explanations and calculations have been given in some detail, but in the other tables they need not be repeated, as the same system has been followed.

TABLE 2.—32 Tests WITH Birmingham Town Gas. ALL ON THE SAME ENGINE, 6 INCHES CYLINDER DIAMETER BY 12 INCHES STROKE.

These interesting and instructive trials are tabulated from the *First and Second Reports of the Gas Engine Research Committee of the Institution of Mechanical Engineers*, London, and were made by Professor Burstall. The author was a member of this Committee. In addition to all the usual figures, Professor Burstall gives the compression pressure, the ratio of the volume of air to that of gas, and the analysis of the exhaust gases leaving the cylinder. In the first set of tests tube ignition was used; in the second the charge was fired electrically. The speeds varied greatly in the first series; in the second they were as far as possible maintained uniform. In both trials it was found that the highest compression gave the highest thermal efficiency, or the most economical results. The best ratio of air to gas for the explosive mixture seems to be about 8½; this, however, requires to be controlled by further tests with all other conditions remaining constant. The engine was four-cycle, single cylinder, single-acting. *Cols. 1 and 2* in both Tables give the test number and the average number of revolutions per minute, which varied from 107 to 207; at 204 revolutions the piston speed equals 408 feet per minute; *Cols. 3 and 4* the I.H.P. and the B.H.P.; the latter varied from 1·3 to 4·1. *Col. 5* gives the heating value of the town gas used which, although coming from the same gas works, varied a good deal, as is often the case, viz., from 540 to 635 T.U. per cubic foot. A Junkers' gas calorimeter was used, and the *lower* heating value was taken. *Cols. 6 and 7* give the number of cubic feet of gas used per I.H.P. and per B.H.P. per hour, including that for the tube ignition in the earlier trials. The gas was measured in a carefully calibrated gas meter. *Cols. 8 and 9* show the thermal

* Most of the leading gas engine builders now guarantee a certain consumption of heat units or calories per H.P.

units supplied to the engine per minute per I.H.P. and per B.H.P. *Col. 10.* The compression pressure in lbs. per square inch absolute, from the indicator diagrams, which varied from 52 to 105 lbs. in the first series, and 55 to 124 lbs. in the second. *Col. 11* gives the proportional volume of air to volume of gas, from 11·7 to 5. The gas was measured in a gas holder carefully calibrated. The temperatures of the air and gas were also taken. The air was measured in a large standard gas meter, through which it was forced by means of a small blower. *Col. 12.* The initial pressures from the indicator diagrams, which varied from a maximum of 286 lbs. to 118 lbs. per square inch absolute. *Cols. 13 and 14* give the analysis of the exhaust gases from the cylinder in percentage volumes of CO_2 and O. *Col. 15.* Percentage of the clearance volume to the total volume of the cylinder. *Col. 16.* The temperature of the cooling jacket circulating water at outlet. *Col. 17.* The original test number. *Cols. 18 and 19.* The heat efficiency per I.H.P. and per B.H.P.; the latter varies from a maximum of 17 per cent. to a minimum of 9·5 per cent. in the first, and 16·7 to 11·9 per cent. in the second series. An average mechanical efficiency of 81 per cent. has been taken for the earlier, and 73 per cent. for the later tests. The author saw this excellent test plant at Birmingham, and was much pleased with all the careful arrangements made to obtain accurate results.

For a complete study of gas or oil engines, and to arrive at exact conclusions, many experiments on the same motor, varying only one set of working conditions at a time, and keeping all others constant, is far more satisfactory than *many* tests on *many* engines. With the latter, all sorts of loads, speeds, compressions, initial pressures, diameters of cylinders, strokes, clearance volumes, &c., are met with. Professor Meyer's is another example of many tests on one engine, and is most valuable (see Tables 3 and 3A). Dr. Slaby was one of the first to set the example in this field, although his tests were made on an old type of engine, and are now somewhat out of date.

Table 3.—12 Tests at Hanover in 1897, by Professor Meyer. All on the same Otto Engine.

These tests have been selected out of 41 made. The engine is four-cycle, single-cylinder, single-acting. Diameter of cylinder 7·8 inches with 11·8 inches stroke. It was therefore rather larger than the one tested by Professor Burstall, Table 2. For full particulars of these careful tests our readers are referred to *Z. V.D.I.*, March, 1899, where all details are given, with drawings and descriptions, in German. The author saw this gas engine and all the arrangements at Hanover. *Col. 1* gives the No. in order of merit; *Col. 2* the original test No.; *Cols. 3 to 6* require no explanation. *Col. 7.* The revolutions per minute from a maximum of 257 to a minimum of 128; at the former speed the speed of piston in feet per minute was about 500. With modern steam engines this figure is often higher. *Cols. 8 and 9* give the metric H.P., differing little from the English. The B.H.P. varied in these tests from 5·4 to 9·9. *Col. 10* is the mechanical efficiency, varying from 69·7 to 85·3 per cent. As in these two tests, the B.H.P. was about the same, probably the lubrication was at fault. *Col. 11* gives the heating value of the Hanover town gas used, which varied very little. *Col. 12.* The cubic feet of gas consumed per hour, from 24·6 to 37·6 per B.H.P. *Col. 13.* The heat used per minute per B.H.P. in T.U., from 217 to 326. *Col. 14.* Ratio of the volume of air to volume of gas, from 6·8 to 9·5. The best results seem to be with a ratio of about 8½ to 9½, and this agrees fairly well with Prof. Burstall's results. *Col. 15* shows the ratio of the clearance volume to the total cylinder volume. Here the higher ratios give the best results, which does not quite tally with Table 2, col. 15. *Col. 16* gives the heat efficiency per B.H.P. in percentage, from a

maximum of 19·4 to a minimum of 13. Comparing these with Table 2, the maximum efficiency is higher. Professor Meyer does not, unfortunately, give in his report the various compression pressures from the diagrams.

Table 3a gives 18 out of a second series of 93 tests made by Professor Meyer at Göttingen, from 1899 to 1902, half being with town gas, half with power gas. As far as the compiler is aware, so complete a set of comparative experiments, made on the same engine, worked under precisely similar conditions, first with lighting, then with power gas, has not hitherto been published. The heat efficiencies with poor gas naturally work out somewhat lower than with lighting gas, as the engine was probably too small to utilise the working agent to the best advantage. (Compare the much better results obtained with the larger engines in Table 5). The tests in Table 3A have been drawn up, as far as possible, on the same lines as Professor Burstall's trials, that they may be the more easily compared. The various columns require no explanation.

In these two tables, as in all the German tests, it must be remembered that the *lower* heating value of the gas has been taken, so that these heat efficiencies may be properly compared with the English efficiencies.

Table 4.—11 Tests on French and German Engines Driven with Lighting Gas.

In the 5 French tests shown in this Table the *higher* heating value of the gas is given. The high heat efficiencies obtained with the engines heading the list are noticeable, and show the great improvements effected in the construction of gas engines during the last few years, as compared with engines built twenty years ago. This is specially observable in the small Koerting engine, No. 2, with a heat efficiency of 36 per cent. per I.H.P. In all the columns the data are the same as before, and need no special explanation.

Table 5.—16 Tests on Different Gas Engines and Generators (for Power Gas) from 1885 to 1903.

The *English and Foreign* trials are arranged, as before, in order of merit of heat efficiency per B.H.P. The heat efficiencies of the generators are also given in the few cases where they were stated by the experimenters. This is why they are called first-class tests. The heat efficiency of a gas generator is the percentage or quantity of heat utilised to the total quantity of heat supplied. In other words, so much heat in T.U. per minute is put into the generator in the fuel (coal or coke), but only a certain percentage of this comes out as gas made, in T.U. per minute, all the rest being lost. Both the heating value of the fuel and that of the gas are generally shown in this table. In the English and German tests the lower heating values are given; in the French, unfortunately, only the higher are returned in the reports. *Col. 1* gives the test No. *Cols. 2 to 8* explain themselves. *Col. 9* shows the mean revolutions per minute, varying from 100 to 202. *Cols. 10 and 11* the I.H.P. and the B.H.P.; the latter varies from 7 to 368. In the Continental tests the metric H.P. has been retained. *Col. 12.* The mechanical efficiency, varying from 69 to 90 per cent. *Cols. 13 and 14.* Lbs. fuel per hour consumed in the particular generator used in each test, both per I.H.P. and per B.H.P. *Col. 15.* The heating value of the gas per cubic foot, as tested in a gas calorimeter. *Col. 16.* The heating value of the fuel put into the generator. To state the lbs. fuel per hour burnt is of little use, unless its heating value is also known. *Cols. 17 and 18* show the number of cubic feet of gas used per hour by the particular engine, both per I.H.P.

and per B.H.P. These quantities are naturally much greater than with town gas, which has a much higher heating value. *Col. 19* gives the heat efficiency of the gas generator, varying in these experiments from 61 to 85 per cent. in the tests where it is stated. *Col. 20.* The heat efficiency of the gas motors per B.H.P., which varies from 29 to 13·7 per cent. *Col. 21* gives references for each test, and the kind of fuel used in the generator for the production of gas.

TABLE 6.—25 Tests ON DIFFERENT Gas Engines AND Generators, 1881 TO 1904, English AND Continental. B.H.P. FROM 3 TO 121.

These, compared with Table 5, may be called *second-class tests*, as neither the heating value of the fuel used, nor that of the gas made, is returned by the experimenter. The order of merit necessarily followed is the lbs. fuel per B.P.H. per hour, but it is unsatisfactory, merely approximate, and of little value. It is, however, often given in rough tests; and as many people like to see them the table and figures have been retained. Without the heating value of the gas and fuel no heat efficiency can be calculated. All the various columns are so similar to those of Table 4 that no explanation is necessary. The lbs. of fuel used per hour in the generators vary from 0·9 lb. to 2 lbs. of coke or coal. The last experiment is with a mixture of coal and wood. The few figures in brackets in Col. 14 are only approximate, as they were not given by the experimenter. Two later tests have been added, in which the heating value of the gas made is given, but not the consumption.

TABLE 7.—10 Tests ON DIFFERENT Motors WORKED WITH BLAST FURNACE GASES. THE B.H.P. VARIED FROM 21·7 TO 725.

These are on German and Belgian engines driving dynamos for power or for electric light. For this new and large development of engines few tests have yet been made. The various columns follow much the same order as in the other tables, and hardly require explanation. The heating value of the gas is lower than that of power or generator gas given in Table 5, and the number of cubic feet used per H.P. is therefore greater. The heat efficiencies per B.H.P. are, however, high—from 18·3 to 26 per cent. Motors for these gases are now being made up to 1,500 H.P.

TABLE 8.—Tests ON DIFFERENT Gas Engines WORKED WITH NATURAL AND COKE-OVEN GAS.

Of the 12 tests here given, 9 are on American engines driven with natural gas, 3 are on the same German engine, driven with coke-oven gas. They are tabulated in the same way as the tests with blast-furnace gases, and the columns require no explanation. The heat efficiency per B.H.P. varies from 27·6 to 14·4 per cent.

TABLE 9.—74 Tests ON DIFFERENT Oil Engines, English AND Foreign, FROM 2 TO 164 B.H.P. 1891 TO 1903.

These are chiefly 4-cycle motors, and are arranged in order of merit of thermal efficiency per B.H.P., which varies much, from a maximum of 32·3 per cent. to a minimum of 5 per cent. The calculations for the thermal efficiencies were made in the same way, as mentioned in detail, for Test No. 1, Table No. 1. *Cols. 1 to 12* speak for themselves. *Col. 13* gives the heating value of the oils used in the motor cylinders. These, as will be seen, do not vary much—only from a maximum of 19,900 T.U. per lb. to a minimum of 18,000. In the 7 French tests at Meaux the *higher* heating values are returned by the experimenter and given here, but in all

the other tests, German and English, the *lower* values are given in each case. This affects, unfortunately, the heat efficiency column somewhat, as mentioned before, but no other method was possible, as the figures could not be altered. The latest results obtained with Diesel and Bánki engines are striking.

TABLE 10.—26 **English Tests** ON **Carriages** AND **Lorries**, MADE IN THE SUMMER OF **1898-9**, CHIEFLY ON **Oil Motors**, BY THE JUDGES OF THE AUTOMOBILE CLUB, AND THE ROYAL AGRICULTURAL SOCIETY.

The first 18 tests were on Oil motors at Richmond driving passenger carriages, English and foreign, of various total weights. They were tested on a run from Southall near London along the Oxford road and back. The author, as one of the judges, witnessed most of the tests, which are given in detail in the judge's report. The same oil spirit was used in all. The maximum speed allowed on the roads was 12 miles per hour, although in some cases it was exceeded. The roads were dry and in good order, and there were many hills. A section of the route is given in the original report. These carriages were also tested separately for hill-climbing capacity on the Petersham Hill, Richmond, which was selected by the judges, having a maximum gradient of 1 in 9½. As these tests come strictly under the head of oil motors, the author has tabulated them. A trained official attendant was on each carriage during the whole time. He noted all incidents, with causes and duration of stoppages, if any. He was also responsible for the measurement of the oil used, &c. With these small motors it is very difficult to measure the variable I.H.P. when running on roads, and in this case it was not done. The question therefore arises how best to obtain a comparative figure of merit as to economy of oil used, and thus to compare these numerous carriages and lorries of very various weights, sizes, types, speeds on road, speeds of motors, different gearing, with one or more cylinders of various diameters and strokes. The author classed them in order of merit of the cost in pence of the oil spirit per ton-mile of total running weight. This was also done for the Birmingham tests of the Royal Agricultural Society by Professor Unwin, F.R.S., and seems an excellent standard to adopt. This cost per ton-mile will be found in Col. 14, and takes count of weight, speed, and cost of oil or fuel. It will be seen that the total weights varied from 0·16 to 1·48 ton. All these little motors go at high speeds, nominally from 600 to 1,400 revolutions per minute, but on the road this varied much. The cost of the oil spirit per mile per ton varied from one farthing to a penny farthing, the same spirit at the same price being used in all the engines. The most economical vehicle ran at only one-sixth the cost of the least economical. The ratio of six times as much spirit per mile per hour is very high, and should be well considered by some of the makers, and the cause ascertained.

Tests 19 to 21, Table 10.—3 **Tests** of **Heavy Vehicles** for carrying loads, also made at Richmond by the Automobile Club, but only for a 20-mile run, and using the same oil spirit as the 18 previous tests on lighter carriages. Total running weight from 8½ to 2 tons. Speed on road from about 4 to 6 miles per hour. The cost of the spirit varied from about one farthing to three farthings per ton per mile. *Col. 16* gives the kind of reducing gear from the motor crank shaft to that of the carriage wheels. For full details of these interesting tests, readers are referred to the judge's report.

Tests 22 to 23, Table 10.—2 **Tests** on **Steam Lorries** for carrying goods, also made at Richmond in 1899, during a 20-mile run. Each had a steam boiler and compound engine, and used coke or coal. One weighed 6·6 tons, and the other 6·9 tons, and ran well at a speed of 5¼ to 5½ miles per hour. The cost of the fuel per ton per mile works out very low.

Tests 24 to 26, Table 10.—**3 Tests** at Birmingham by the judges of the Royal Agricultural Society in 1898, on **Lorries** for goods, during a run of nearly 47 miles. One was an oil, and the other two steam motor cars. The weights varied from 2½ to 6½ tons. Speeds on road 6¼ to nearly 8 miles per hour. The cost per mile per ton was also very low. The author as one of the judges witnessed these tests, and could testify to the care bestowed on them. These few steam tests are added to form a comparison with the oil motors.

It may be of interest to add some notes from Professor Unwin's able report on the Birmingham Royal Agricultural Society's tests, where he was one of the judges. From the experiments made he calculated the H.P. that would be required on a level road, and also going up a hill of a gradient of 1 in 12. His results are as follows :—*With No. 24.* **Daimler Oil Engine**, of a total weight of 2·49 tons, going on a level good road at a speed of 7·8 miles per hour, the B.H.P. should be about 2·6. On a rising gradient of 1 in 12, at an assumed speed of 3·9 miles per hour, the power required is about 6·2 B.H.P. *With No. 25.* **Thornycroft Steam Motor Car**, of 6·9 tons running weight, on a level road at a speed of 6·2 miles per hour, the power should be about 8·2 B.H.P. For a rising gradient of 1 in 12, and at 4·1 miles per hour, 14·7 B.H.P. *With No. 26.* **Lancashire Steam Motor Car**, of 6·54 tons, on a level road at 6·5 miles per hour, 9·4 B.H.P. On a gradient of 1 in 12, at 3¼ miles per hour, 15¼ B.H.P. These figures are the effective or B.H.P. ; to get the I.H.P., the power required to drive the motor, and that for the gearing between the motor and the wheels of the vehicle, must be added.

These 26 tests appeared in a paper on Road Locomotion by Professor Hele Shaw, F.R.S., read before the Institution of Mechanical Engineers, 1900.

Table 11.—**13 Tests** on different **Air Engines, English** and **Foreign.**
Requires no explanation.

APPENDIX B.

ABSTRACT TRANSLATION OF BEAU DE ROCHAS' CYCLE.
(French Patent, 1862.)

Concerning Compression in a Gas Engine.

. . . . . The conditions for perfectly utilising the elastic force of gas in an engine are four in number :—

I. The largest possible cylinder volume with the minimum boundary surface.
II. The greatest possible working speed.
III. Greatest possible number of expansions.
IV. Greatest possible pressure at the beginning of expansion.

The characteristic of gases to disperse over a given area can be turned to excellent account in pipes, but is, on the contrary, evidently an obstacle to the utilisation of the elastic force developed in the gaseous mass. It has been shown [in a former part of the patent] that in pipes the utilisation—that is, the heat transmitted—is in proportion to the diameter of the pipe. In cylinders, therefore, the loss would be in inverse ratio to the diameter, but this only applies to cylinders of very small diameter, and the loss really diminishes more rapidly in proportion to the increase in diameter. Thus the typical design, which, for a given expenditure of gas, assigns a cylinder of the largest diameter, will in this respect utilise the most heat. We may also conclude that, as far as possible, only one gas cylinder should be used in each separate engine.

But the loss of heat in the gas depends also on the time. Other things being equal, the cooling will be greater the slower the speed. Now, greater speed seems to entail a cylinder of small volume; but this apparent contradiction disappears if we remember that, for a given consumption of gas, the stroke is not necessarily and invariably limited to the volume of the cylinder.

In utilising the elastic force of gas, it is necessary, as with steam, that expansion should be prolonged as much as possible. In the typical design described above, there is a maximum of expansion for each particular case, although the effect is necessarily limited. The arrangement will, therefore, give the best result, which restores to the motor what may be called its liberty of expansion, that is to say, the power of expanding as much as may be thought desirable, within practical working limits.

Lastly, the utilisation of the elastic force of the gas depends upon a function closely allied to prolonged expansion and its advantages. This is the pressure, which should be as great as possible, to produce the maximum effect. Here the question clearly is to obtain expansion of the gases when they are hot, after compressing them while cold. This is to a certain extent an inverse method of prolonging expansion to that employed when a vacuum is formed. The latter process is not at all suited to gases, because all such compression necessitates an equivalent condensation, and even supposing the gases were combustible, it would be impossible to heat them instantaneously.

Theoretically, therefore, it is possible to utilise the elastic force of the gases with-

out limit, by compressing them indefinitely before heating, just as the elastic force of steam may be utilised without limit, by prolonging expansion indefinitely. Practically an impassable limit is attained as soon as the elevation of temperature due to previous compression causes spontaneous combustion. If compression be then continued, the work done by it would be represented by expansion prolonged to the same point, less the loss caused by all useless work. The natural limit is here reached, and the arrangement which best attains it will utilise to the most advantage the heat supplied.

The question of heat utilisation being thus stated, the only really practical arrangement is to use a single cylinder, first that the volume may be as large as possible, and next to reduce the resistance of the gas to a minimum. The following operations must then take place on one side of the cylinder, during one period of four consecutive strokes :—

I. Drawing in the charge during one whole piston stroke.

II. Compression during the following stroke.

III. Inflammation at the dead point, and expansion during the third stroke.

IV. Discharge of the burnt gases from the cylinder during the fourth and last stroke.

The same operations being afterwards repeated on the other side of the cylinder in the same number of piston strokes, the result will be a particular type of single-acting, or half-acting engine, so to speak, which will evidently afford the largest possible cylinder, and what is still more important, previous compression. The piston speed will also be greatest in proportion to the diameter, because the work is performed in one single stroke, which would otherwise occupy two. Clearly it is impossible to do more.

As the temperature of the gases coming from a furnace is practically constant, and that of the external atmosphere varies relatively only within narrow limits, the initial temperature of the mixture at the moment of admission into the cylinder will also be practically constant. It will, therefore, be possible to determine the limit of compression at which combustion is produced, and to make the design of the engine conform to it. Thus the maximum effect will always be obtained, for each proportional dilution of the combustible. At the same time there will be no necessity to use electricity, because the starting of the engine being determined by the action of the steam (*sic*), the gases might be admitted only when the speed has become great enough to produce spontaneous inflammation. In any case compression, by helping to mix the charge thoroughly and by raising its temperature, would be favourable to instantaneous combustion. If the initial temperature in the generator corresponded to a pressure of 5 or 6 atmospheres, inflammation would be spontaneously produced if the gases were compressed to about a quarter of the original volume, the effect of loss of heat being neglected. After complete inflammation the pressure would be hardly 30 atmospheres, and as combustion would be effected without excess of air, the pressure would in any other case (*i.e.*, where an excess of air was admitted) be necessarily less. Probably, therefore, in many cases, the absolute limit of utilisation of the heat may be attained.

We may sum up the question by saying that, although the typical arrangement here described can be most completely and perfectly adapted to the utilisation of the elastic force developed by combustion at constant volume in the gaseous mass, it is quite simple. It is perhaps rather a convenience than a necessity to use lift-valve distribution. This is generally the best method, and nothing proves that it may not be applied to the four-cycle type of engine.

APPENDIX C.

SUMMARY OF EXPERIMENTS ON A TWIN-CYLINDER OTTO GAS ENGINE.

By Dr. A. SLABY.

Object.—These valuable experiments were made by Dr. A. Slaby, Professor at the Technische Hoch-Schule, Berlin, to investigate the heat cycle in a gas engine. The object with which they were undertaken was, in Dr. Slaby's words, to "determine by measurements the division of heat in a gas engine, in order to deduce therefrom the conditions for the best utilisation of the combustible." They have been published from 1890 to 1892 in six pamphlets, comprising 196 pages, illustrated by many plates and diagrams, and form an exhaustive treatise on the subject. An abstract of their contents is here given. Dr. Slaby's laborious researches were among the first contributions to that thorough study of the phenomena taking place in a gas engine cylinder, on which alone the true theory of the gas engine can be based.

The motor experimented on was a twin-cylinder horizontal 8 H.P. German Otto engine, employed for driving various machinery in the Berlin Technical High School. The gas used was always lighting gas, made from Upper Silesian coal, from the gas-works at Charlottenburg, near Berlin. The diameter of the cylinder was 172·5 mm. = 6·8 inches, and stroke 340 mm. = 13·3 inches. In all, 306 experiments, divided into two sets, were made, from 1886 to 1890.

Heating Value of the Gas.—Pamphlet I.—The author begins by expressing his desire to elucidate the various questions still undecided in the theory and practice of the gas engine. With this object it is necessary, he considers, first to determine the composition and heating value of the gas used. The chemical constituents of any gas depend upon the raw material (coal), the process of generation and purification, and the time which has elapsed since the beginning of distillation. But the difficulty of arriving at an exact knowledge of the heating value and composition of any given gas is great, sometimes almost insuperable. All that can be done, to ensure uniformity in the constituents of lighting gas during a test, is to carry out the experiments always at the same hour of the day, with gas from the same main.

Not only is the composition of gas given differently by different authorities, but the proportions of heavy hydrocarbons are variously estimated. Some writers class them all as C_4H_8, some as C_2H_4, some as half one, half the other, producing a difference in the heating value of the gas of 8 per cent. This method was not sufficiently accurate for the author's purpose. After many trials he found that the heat value of each hydrocarbon could be expressed as

$$H = 1{,}000 + 10{,}500 \times \text{the density of the hydrocarbon}$$

(H representing the heating value in calories per cubic metre), and that this formula was also applicable to any given mixture of the same. It was necessary, therefore, to determine the density of each gas to within $\frac{3}{4}$ per cent., instead of

taking the residuum in the gaseous mixture, after analysing the different constituents H, CH_4, CO, &c., as nitrogen, and reckoning its weight as such.

To calculate the density of the hydrocarbons, a Schilling apparatus was used, of which a drawing and detailed description are given in the original. By this instrument it was found that the densities of any two gases were inversely proportional to the squares of their speed of discharge, at the same pressure, through a narrow orifice. The experiment being carried out first with air, then with gas, the density of the latter was thus determined. Great care was taken to ensure an even temperature. Satisfactory results were obtained by these means, but it was necessary to check them by experimenting upon perfectly dry lighting gas; the Schilling apparatus being immersed in water, the gas in it was always slightly damp. The difference between moist and dry gas was considerable. *Saturated air weighed* 0·75 *per cent. less than dry air, but saturated gas weighed* 0·94 *per cent. more than dry gas.* The gas was next directly weighed. Two glass vessels were filled respectively with dry gas and dry air, and after being both brought to the same temperature and pressure, they were weighed. Immediately after, the glass vessels were weighed alone, and the proportional weights of the gas and air thus determined. The correction for the Schilling apparatus was found to be only 0·07 per cent., but this accuracy was obtained after years of practice, comprising about 1,000 determinations. Finally the Lux gas weigher was used, and gave excellent results, about 3·8 per cent. higher than the Schilling, owing to the dryness of the air and gas, and faults in calibrating.

To determine the heat value of lighting gas, the percentage in volume of the heavy hydrocarbons was ascertained by analysis. The specific weight of the gas being known, and the residuum taken as pure nitrogen, the specific weight of the heavy hydrocarbons was deduced from the weight of the gas with and without them. This method has the disadvantage of assuming that the residuum consists entirely of pure nitrogen, whereas it is known to contain ammonia and other substances. A more satisfactory process was as follows:—The gas was first carefully weighed, then passed through tubes and vessels containing glass shavings, sulphuric acid, potash, water, &c., to separate the hydrocarbons and carbonic acid. The purified gas was then again weighed, and the density of the heavy hydrocarbons found by deduction to be a mean of 1·72. This agreed well with the ordinary analysis of Berlin gas. It may therefore be assumed that in any given gas the mixture of heavy hydrocarbons is essentially a constant, the greatest difference in the heat value being 8 per cent. During one day of a trial, the difference was seldom more than 1 per cent. It is necessary, however, in making an experiment, to determine the heat value of the mixture of heavy hydrocarbons, which vary from 13,000 to 27,000 calories per cubic metre. Throughout the experiments it was taken at 19,000 calories per cubic metre.

Products of Combustion.—In the **Second Pamphlet** the composition of the products of combustion is considered, and the constants determined. The specific weight of 1 cubic metre is 0·417, with a heating value of 4,883 calories. For complete combustion the weight of oxygen required for 1 cubic metre of lighting gas is 1·515 kilos., and of air 6·425 kilos. or 4·965 cubic metres. The combustion produces 6·965 kilos. or 5·684 cubic metres of products, or a contraction of 4·8 per cent. Analyses of the products of combustion with different dilutions of air were carried out on seven different days, and the mean taken. In none of them could any trace of unburnt hydrocarbons or carbonic oxide be discovered. These analyses do not give the percentage of steam, which is certainly superheated, and is reckoned, for the above proportions, at 1·209 cubic metre. The different constants for propor-

tions of 5, 6, 7, and 8 volumes of air to 1 of gas are shown in a table and plotted out, namely—Percentage of contraction during combustion; weight and specific weight of 1 cubic metre of the mixture before combustion, and of 1 cubic metre of products; and constants of the products.

The next question to determine was the specific heat of the products of combustion. The author distinguishes between true and mean specific heat; the former increases twice as much for a given increase of temperature as the latter. The increase in true specific heat per degree rise in temperature, for the gas composing the products of combustion in a gas engine, is given from Mallard and Le Chatelier, and the values calculated at constant pressure, and at temperatures of 0°, 100°, 500° 1,000°, 2,000° C. From these the specific heats, at constant pressure, of the products of combustion under the same conditions are reckoned, and plotted out. The horizontal lines show the rise in temperature of the gases from 0° to 2,000°, the verticals the increase in their specific heat at constant pressure, for a given dilution of gas and air.

Engine and Instruments.—The experiments to verify these calculations were carried out on the engine already described (drawings of which are given by Dr. Slaby). The quantities of gas, air, and of cooling water were carefully measured. During the experiment only one cylinder was used, the other being employed to determine the piston friction. The quantity of gas was measured by a glycerine gas meter, marked to show half litres, the consumption for the ignition flame being given by a separate meter. Both meters were carefully tested before the experiments, and thermometers inserted in them, from which the temperatures could be read off. From the meters the gas passed to the engine through rubber bags, a pressure gauge being fixed in the admission passage. In all the experiments the air was measured in a gas meter, provided with a scale, thermometers, and pressure gauge. The error in this meter was found to be under ½ per cent. The air was forced into the air meter by means of a small fan, driven by a little water motor. The pressure was determined by passing it, before it entered the meter, through a small air holder maintained by weights at a constant height. The cooling jacket water passed to the engine through pipes in which small copper tubes were inserted, one at the entrance, the other at the exit; these tubes contained delicately graduated thermometers. The quantity of water was previously measured in gauged tanks, and afterwards passed into another tank.

The governor was not acting during the experiments. The opening admitting the gas could be adjusted by means of a screw, but in the trial the mixture was kept uniform, with the same proportion of gas. Speed counters were arranged on the crank shaft and valves.

Temperature of Gases at Exhaust.—The next question was to determine the temperature of the gases of combustion. The author began by taking the temperature with pyrometers fixed in the exhaust passage, but found an error of 50° in the best instruments. He next operated with ordinary glass, quicksilver, and nitrogen thermometers, marking up to 460° C. By cooling the cylinder very considerably, and greatly reducing the speed, it was possible to reduce the temperature of the exhaust gases to the desired limit. No practical results were, however, obtained until a ball calorimeter was used. In the ordinary exhaust pipe a cock was fixed, which, when open, allowed the gases to pass in the usual way into the atmosphere. When closed, the gases of combustion were forced through another channel, joining the main exhaust pipe at a point below the cock. In this pipe was a hollow cock, the socket of which contained an iron ball. By turning the cock 90° either way the ball could be introduced into the socket, or allowed to fall out below. To make an

experiment, the gases were first shut off from their usual course, and the side cock opened, causing them to flow through an auxiliary pipe. The ball being previously placed in the socket, and kept in position by wire-netting, it was exposed for half an hour to the current of the hot exhaust gases. A calorimeter containing water was then placed beneath it, the cock turned, and the ball dropped into the calorimeter, when its temperature was determined in the usual way by the rise in temperature of the water. The author thus succeeded in obtaining accurately the temperature of the exhaust gases which, plotted on a curve, were compared with those arrived at with an ordinary thermometer.

The indicators employed were of various kinds. No brake was used on the engine during the experiments, because the author, who worked for the most part entirely without help, was not able to carry out brake at the same time as calorimetric experiments. The brake efficiency was at other times carefully noted.

Volume of Clearance Space.—The compression or clearance space of the engine was 60 per cent. of the total suction volume of the piston. This was determined—1, By direct measurement of the internal dimensions of the cylinder; 2, by filling the cylinder with water, and thus measuring both the compression space and volume swept through by the piston.

Piston Friction.—The piston friction was next calculated, the heat thereby generated affecting materially the heat balance of the motor. This was done by shutting off one of the two cylinders, and running it without gas; the rise in temperature of the jacket water gave the heat due to the piston friction. Seven experiments were made on two different days, and 50 litres of circulating water used. The trial varied from half an hour to an hour and a half, and the rise in the temperature of the water, corrected for the heat of the room (which was always about 3° higher than that of the water at discharge), varied from 5° to 8°. The heat carried off per cycle varied from 0·09 to 0·13 calorie. The mean temperature of the walls was about 3° below that of the water at discharge.* The results, when plotted out, showed that the friction of the piston decreased with the rise in temperature of the walls for about the same number of revolutions; in other words, the higher the temperature of the walls, the less heat was carried off by the jacket water, or the less friction was generated. This was clearly revealed by the experiment of the 21st April, 1888, and the piston friction was found to depend not on the speed, but on the mean temperature of the walls. Thus with a mean wall temperature of 9·4°, the heat generated by the piston during two revolutions, or one cycle, was 0·183 calorie, with a wall temperature of 15·6° it was 0·17 calorie. The speeds varied from 97 to 182 revolutions per minute. These results are worked out and summed up in a table, showing the generation of heat by piston friction, with a wall temperature of 10° to 55°. Taking into account the indicated work, the author arrived at the conclusion that *the lower the wall temperature the greater the friction.* With a temperature of 10°, nearly one-third the indicated work was expended in piston friction; it sank to 6·5 per cent., with a wall temperature of 40°, corresponding to a temperature of the water at discharge of 70°. If it were possible to reduce the wall temperature to 3°, the engine would not be able to overcome the frictional resistance.

General Cycle.—Pamphlet III.—The amount of heat turned into indicated work during a complete cycle in a gas engine, is influenced by the following factors:—1, Heat value of the gas; 2, piston speed; 3, temperature of the walls; 4, proportion in which the gas is diluted with air, or with neutral gases; 5, amount of compression before ignition. To study a gas engine properly, each of these five should be sepa-

* The temperature of the cast-iron cylinder wall was always taken as a mean between the temperature of inlet and outlet of jacket water.

rately varied, the others being maintained constant. The heat value of the gas having been already considered, the next question is the influence of the piston speed. The author found that his experiments did not confirm the general opinion that the efficiency increased with the speed. The gas consumption per I.H.P. per hour, when the engine was running at 87 and at 180 revolutions per minute, was practically the same, the temperature of the out jacket water varied only 2° or 3°. The I.H.P. was more than one-third higher at the above high speed, but the negative work was greatly increased. "As these results were questioned," says the author, "I repeated my experiments in sets of two together on the same day, and proved that, if a motor is allowed to run continuously for some time, and the speed be increased, certain phenomena intimately connected with it make their appearance, which not only counterbalance the favourable effect of the augmented speed, but act prejudicially in the opposite direction. These influences are principally manifested by the rise in temperature of the products of combustion, and the increase of the negative work, corresponding to the periods of exhaust and admission in the gas engine. The increase in negative work was revealed by the indicator which, with a weak spring, showed that the mean pressure corresponding to the negative work rose from 0·070 kilo. per square centimetre when the engine was running at 92 revolutions, to 0·242 kilo. per square centimetre at 191 revolutions. The temperature at which the products were discharged rose at the same time more than 150°."

Two series of experiments were undertaken to determine the influence of the speed, and yielded results at variance with those obtained by Professor Witz. The temperatures of the jacket water and exhaust gases were measured as described.

The cycle of the gas engine was divided into—1, Admission; 2, Compression; 3, Ignition; 4, Expansion; 5, Discharge, and each of these periods was studied experimentally.

Considering first the admission period, the author found that though the proportion of air to gas varied a little, the mean temperature of the jacket water, or that of the walls, rose slightly, though not in every case, and the temperature of the exhaust gases always, in almost exact proportion to the increase in the speed. With 90 revolutions the exhaust temperature was 400° C., and with 170 revolutions 529° C. The total volume of the charge drawn in per stroke decreased with increase of speed; with double the revolutions it fell more than 20 per cent. This proportion varied in the different experiments, the difference being less, the higher the speed. It was clearly a result of the available admission volume, which was dependent on the pressures at beginning and end of the cycle, and upon the mean temperatures at these two periods. To determine the pressure during admission, it was necessary to know how far the line of admission varied in pressure from that of the atmosphere. This initial pressure was found to increase in almost exact ratio to the increase of speed, from whence the author concluded that it *depended entirely upon the number of revolutions.*

Other experiments on the back pressure of the exhaust gases showed that, at the moment the exhaust valve closed, the pressure line rose slightly, in fairly exact proportion to the number of revolutions. It was always higher with increase of speed, varying from 8 mm. with 98 revolutions, to 14 mm. with 184 revolutions (scale —29 mm. = 1 kilo. per sq. cm.). Plotting out the values obtained, the author found that, however the conditions of discharge were varied, the pressures always rose with the increase of speed, but much more gradually after the engine had been running for an hour, and a certain equilibrium in working was obtained. Thus the exhaust as well as the initial pressure depended entirely on the speed.

The temperatures at admission and discharge of the gases remained to be con-

sidered. The first the author had no means of determining. The temperature of the products of combustion left in the cylinder is about the same as that determined with the calorimeter and ball, but at the moment the exhaust valve opens, the author verified a sudden momentary rise of 2° or 3°. Nevertheless he assumed that the mean temperature of the products in the cylinder, and of the exhaust gases, was the same. The temperature of the exhaust gases was higher in the one set of experiments than in the other, about 3 per cent. absolute temperature at 150 revolutions, although the speed and the volume of the charge were the same, and this was explained by the difference in pressure, which was 14 per cent. By itself this difference should have produced a higher exhaust temperature; but the mean temperature of the walls was on the other hand 5° lower, thus showing their influence on the temperature of the exhaust. The temperature of the charge in the cylinder at the end of admission was obtained by calculation. Plotted out on curves, the figures showed that this temperature also increased with the speed, but not much. With double the number of revolutions, the increase was only from 106° C. to 128° C. The two experiments showed the same variation of temperature as before verified, about 7° at equal speeds (150 revolutions). Hence the mean temperature of the products left in the cylinder had but a slight influence upon the mean temperature of the freshly admitted charge. The author was able to determine with certainty that the temperature of the charge at admission was about 100° higher than that of the cooling water at discharge.

He sums up these researches by stating that the differences in the volume of the charge can be explained only by these differences of pressures and temperatures, which he formulates thus—

$$\frac{\text{pressure at admission of charge}}{\text{abs. temperature at admission of charge}} = 31 - 0{\cdot}049 \times \text{number of revs.},$$

$$\frac{\text{pressure at exhaust}}{\text{abs. temperature at exhaust}} = 22{\cdot}64 - 0{\cdot}0238 \times \text{number of revolutions.}$$

These were the values for the first set of experiments. They differed in the second experiments chiefly in respect to the exhaust temperature and pressure, which, unlike the admission pressure and temperature, *depended on the mean wall temperature as well as the speed.*

Walls during Admission—Speed Effect.—The author next endeavoured to determine the action of the walls during admission, their temperature being then lower than that of the gases in the cylinder. The difference between the heat given off by the products in the cylinder, and that absorbed by the fresh charge passes into the cooling water, and it is necessary to know the weights of the products, of the gas, and of the air composing the charge. The weight of the products he found to diminish in *exact* ratio to the increase of speed, being with 90 revolutions 3·21 grammes, with 184 revolutions 2·88 grammes. The specific heat of the products increases. On the other hand, the heat carried off to the cooling water during admission increases greatly with the speed. In the first set of experiments it rose from 0·08 cal. to 0·16 cal., the speed being doubled, and in the second from 0·02 cal. to 0·10 cal. for the same increase of speed, the temperature of the walls in the latter case being about 5° higher. "It follows," says Dr. Slaby, "that for the heat given off to the walls the rise in temperature of the products, increasing with the speed, has a far greater effect than the diminished time of contact with the walls."

Hence he deduces that the pressures and temperatures at admission and exhaust are variable, and depend on the speed, and the mean temperature of the walls.

The admission pressure and temperature depend on the speed, and are but slightly affected by the temperature of the products with which the fresh charge mingles, and that of the cooling water. The exhaust temperature and pressure are greatly affected by the walls. If no water is allowed to collect in the exhaust pipe, the pressure of exhaust becomes a function of the speed, and the proportion of pressure to temperature of exhaust, the wall temperature and dilution of the charge being maintained constant, can be approximately calculated from the speed. Thus formulæ are obtained for calculating the volume of the charge admitted per stroke, the total weight (including that of the products) and quantity of heat given to the cooling jacket. The author considers that the greater the number of revolutions the smaller the charge, and he says further :—"If the quantity of gas admitted is smaller at high than at low speeds, it will be evident that the difference between the heat given off by the products during admission, and the heat taken up by the freshly admitted charge must be considerably increased by increase of speed."

Indicators—Pamphlet IV.—The least known part of the gas engine cycle is that comprising the ignition and expansion of the charge. There is only one way of determining the connection between the spread of the flame and the cooling influence of the walls, namely, an analysis of the indicator diagram. The author, therefore, devotes the whole of this pamphlet to an exhaustive study of indicators, (Crosby and others), and a determination of their limits of error. The indicators chiefly used during the experiments were a Crosby and a Storchschnabel.

Compression.—Pamphlet V. deals with compression in the gas engine. During this period the amount of heat set in motion and its direction should be determined. The problem is simple, if the compression curve be replaced by a "polytropic"* curve.

$$p\,v^m = \text{const.}$$

The initial pressure having been shown to depend entirely on the speed, the compression pressures must be taken from the diagrams. The mean pressures for two sets of experiments are given in tables, and when plotted out, the abscissæ representing the number of revolutions, and the ordinates the pressures of compression in millimetres above atmosphere, these compression pressures are shown to follow a strict law, and to decrease in proportion to the increase in the speed. This law the author reduces to a formula. From the two sets of experiments he lays down the proposition that *the compression pressure depends entirely upon the speed of the engine, and can be reckoned by a given formula.* Desiring next to know if the compression curve agreed with the polytropic during its whole course, he calculates the pressures, at half way through the stroke, from all the diagrams of the second set of experiments. They were also found to diminish with increase of speed, though not to the same extent as the initial pressures, and thus the compression curve agreed with the polytropic throughout its course, and could be accurately calculated, the exponent being 1·29. To prove its variation from the adiabatic, the author reckoned the specific heat for both curves at constant pressure and volume of the mixture of gas, air, and products. It was considerably higher for the adiabatic than for the polytropic curve, with which he had proved the compression curve to agree, and hence he concludes that *during compression there is a loss of heat to the walls.* Other conditions being equal, this compression pressure is a function of the speed. Thus at 100 revolutions, the initial pressure being

* "Polytropic" is the name given by Zeuner to any curve which can be represented by the formula $p\,v^m$ = constant. The isothermal and adiabatic curves come under this law, with different exponents, m; the polytropic may be called the generic curve, of which the isothermal and adiabatic are varying forms. For a full explanation of the law, see Zeuner, *Thermodynamik*, and Schöttler.

atmospheric, the pressure of compression is 3·50 kilos. per square centimetre; at 200 revolutions (double speed) it is 3·06 kilos.

The mean temperature during compression increases with the speed. With a mean temperature of 200° C. the specific heat of the products of combustion is 11·5 per cent. higher than at 0°. The mean rise is 130°, the proportion between the initial and compression temperatures remaining constant at 1·32. The work of compression, especially the increase in the internal work, also depends upon the speed. The change of condition is accompanied by a carrying off of the heat, but this abstraction of heat is small, and slightly diminishes with increase of speed.

Ignition Period.—The next question considered is the ignition period. This can only be studied by the help of the indicator diagrams taken by the author in each experiment. The differences in the diagrams obtained under precisely similar conditions the author attributes to the varying composition of the gas mixture which, even if the valve action is perfectly regular, is subject to uncontrollable fluctuations, due to slight differences in the speed of ignition. It is well known from Mallard and Le Chatelier's experiments that the speed of ignition increases up to a maximum with increasing richness in the gas mixture, but if the proportion of gas be still greater, it falls again. The indicator diagrams showing the effect of a richer or poorer mixture give curves sinking regularly one below the other with the decrease in the proportion of gas in the mixture, but do not explain the variation in the rounded shape of the top of the diagram. The author does not attribute this to the ignition flame, but considers that it is probably caused by differences in the local arrangement of the charge, and not by fluctuations in the strength of the mixture, which can hardly occur when the engine is running regularly. The small, perfectly vertical part of the indicator diagrams obtained by him is due to the force of the explosion in the ignition port; the rest of the line, deviating more or less from the perpendicular, represents the ignition of the remainder of the charge. At the top of all diagrams (taken with double springs) he found a distinct "nick," marking the point where expansion and fall of pressure began. To this, the point of highest temperature in the cycle, he devoted careful study.

Considering first the temperature and pressure of compression, and of this maximum point in the diagram, he reckons the mean specific heat of the charge at constant volume from that at these two points. The amount of heat shown by the diagrams in the area enclosed between the point of highest compression and of maximum temperature (ignition), the atmospheric line and the corresponding ordinate of pressure, is always less than that set free by the combustion of the gases. This difference in heat must be accounted for in one of three ways. Either it is developed during this period, in which case it must be entirely absorbed by the walls; or incomplete combustion, "nachbrennen" takes place; or both processes are combined. Analyses of the products prove that, at some period of the stroke, there is perfect combustion of the whole gaseous mixture. If the heat passes into the walls, the amount thus transferred must be in proportion to the surfaces in contact, time of exposure, and difference of temperature. If "nachbrennen" is produced, it must depend on the proportional composition of the charge, and on the speed, and be increased by poorer mixtures and greater speeds. The figures obtained by the author show, especially with reference to the speed, that this is *not* so. Taking the difference between the total heat of the charge at this point of the stroke, and the heat of combustion shown in the diagrams, and plotting them out, the author finds the percentage of this difference to be higher with low than with greater speeds, being 8·5 per cent. with 179 revolutions, and 13·2 per

cent. with 100·6 revolutions. At 150 revolutions about 10 per cent. of the total heat disappeared. As neither the surfaces nor the maximum temperatures vary much, the differences producing this loss of heat must lie in the time of wall contact. If all this heat passes into the walls, it will be proportioned to the time the indicator pencil takes to travel from the compression to the ignition point, or what the author calls the "time of ignition." The phenomenon cannot be caused by irregularities in the action of the engine, because these, when tested for time with the usual tuning-fork apparatus, were found to be less than ½ per cent.; the speed was therefore constant.

The author proceeds to find the angle through which the crank passes during this period, and expresses in a formula the proportion between the distance passed through, and the angle of crank revolution. By these means he was able to determine the time occupied in traversing the distance, in proportion to the speed, which, when plotted out, showed that the shorter the time the less heat disappeared. The increase in the heat lost was proportioned to the duration of combustion. Hence the author assumes that, *at the point of highest temperature combustion is ended, and the heat not shown in the diagrams has wholly passed into the walls.*

Speed of Ignition.—Having thus arrived at the time of ignition, the author was able to determine approximately the speed of ignition. By calculation and measuring the diagram, he reckoned the total length of the ignition channel in proportion to the length of stroke, and was thus able to express the ignition speed in a formula. This speed of ignition was nearly doubled with twice the number of revolutions, being for 100 revolutions 2·6 metres per second, and for 180 revolutions 4·5 metres. These figures agree with Mallard and Le Chatelier, who found that the speed of ignition increased greatly when the gas was in a state of violent motion, and attributed the phenomenon not only to conduction, but to differences of speed in the component parts of the gas. As the charge in a gas engine must be in violent motion during ignition, combustion is really complete at the point of maximum temperature, between ignition and expansion. Thus there is a sudden explosion and rise in pressure at first, then a powerful flame darts into the cylinder, and with a smaller speed of propagation ignites the whole charge. This speed of propagation is affected by—Composition of the mixture; speed of the engine (shown in the more rapid motion produced in the cylinder); the particular local stratification of the gaseous mass, whether homogeneous or otherwise. Combustion is completely ended in from 0·03 to 0·06 second, corresponding to the maximum mean temperature, after which expansion, without addition of heat, takes place. No dissociation is possible, since the maximum temperature is never above 1,600° C. During combustion the flame certainly comes in contact with the walls, and transfers to them some of its heat. But this is only from 8 to 13 per cent. of the total heat, and therefore, considering the difference between the heat conductivity of the metal and that of the products of combustion, we may conclude that this contact does not last long. The process of combustion chiefly takes place in the kernel of the charge, surrounded by neutral gases. The author therefore is of Otto's opinion, and considers that the composition of the centre of the charge not being homogeneous, a more favourable economic effect is produced.

Expansion Period.—Pamphlet VI. treats of the period of expansion. The author calculates the heat lost to the walls during this period from the difference between the area of work in the diagram, and the total heat of the gaseous mass. The expansion curve he divides into sections, and traces polytropic curves from one ordinate of pressure to the next. The exponent, already given, is governed by the speed. The values thus obtained are plotted out, and when compared with true

adiabatic curves, the author found that during expansion *there is a continuous carrying off of a large amount of heat to the walls, the temperature falling at first, and then rising.* This is explained by the combined influence of the decreasing temperature and increasing wall surface exposed. At the beginning of expansion, the quantity of heat carried off is determined by the temperature, at the end of expansion by the cooling wall surface. It is only at a speed of 400 revolutions per minute that the expansion curve approximates to the adiabatic.

Considering next the fact, shown already to be probable, that during expansion no increase of heat is produced by internal heating, the heat parted with externally must be at the expense of the internal energy of the gas. This can be calculated from the temperatures and the corresponding specific heats at constant volume. The difference between this internal energy and the external work done shows the amount of heat imparted to the walls. These three quantities can be expressed either as heat or as work. As work they may be measured on the indicator diagram as functions of the lengths of stroke, and represent the divisions of heat. The two quantities of internal and external heat are reckoned for any given portion of the stroke, converted into units of work, and divided by the volume passed through by the piston. Plotted out, they show that the abstraction of heat by the walls follows a regular course. At first the walls are relatively very cool, and the temperature of explosion very high. As the wall temperature rises, less heat is abstracted, and at the end of combustion a minimum is reached. The heat curve now rises, because the cooling surfaces are increased by the out stroke, but about the middle of the stroke another fall is produced by the increased piston speed. It again rises at the end of the stroke, as the speed is reduced. These curves show only the amount of heat actually abstracted, and do not enable us to verify the progress of combustion, and whether part of the heat carried off is developed by "nachbrennen." They reveal, however, that the heat parted with to the jacket during expansion, is inversely as the speed. The higher the speed, the less heat is carried off.

Exhaust Period.—This may be divided into two parts. During the first, occupying the last tenth of the forward stroke, a portion of the gases escape, carrying off part of the total energy of the charge, in the shape of "*force vive*," or "energy of exhaust" (as Zeuner calls it). The remainder of the gases are discharged at lower speed during the return stroke. The author endeavours to determine the heat value of this "energy of exhaust" from the heat balance of the engine. The heat received is the heat set free by the combustion of the lighting gas. The heat going out is divided into—1, Indicated work, both positive and negative, measured from the area of the diagrams, and reduced to calories. 2, Heat passing into the walls and carried off into the cooling water, less the heat absorbed in piston friction. The latter heat value is calculated, as before stated, from the rise in temperature of the jacket water and the quantity used, which was always 200 litres; the time of passing this quantity through the jacket varied from fourteen to twenty minutes. 3, The appreciable heat carried off in the products of combustion. The weight of the products is known, being the same as the weight of gas and air admitted per stroke. Their mean temperature is calculated from the weight of the gas and air, plus their specific heat at constant pressure, and the difference between the temperatures at admission and exhaust. The values obtained are shown in a table. 4, Heat value of the work of resistance during exhaust. This is reckoned from the difference in volume, namely, the increase during the time from the opening of the exhaust valve to the end of the stroke (about one-tenth of stroke), and is distinct from the heat value of the return or exhaust stroke. 5, The "energy of exhaust," or the momentum of the products at the beginning of

exhaust, shown by the difference between the pressure at the opening of the exhaust valve and the constant back pressure during the return exhaust stroke. This difference is plotted on a curve.

The variations shown are referred by the author to the accumulated action of the walls. Time is necessary, that the metal may reach a state of thermal equilibrium. At the beginning of an experiment the walls are still affected by the preceding trial, and contain more or less heat, according to the previous speed of the engine. In this way the author determines the heat accumulated in the walls, that taken up by them, but not carried off in the cooling jacket, and that withdrawn from the walls, but not from the cycle. The values obtained for this "energy of exhaust" give the mean speed of the gases during the last tenth of the forward stroke, reckoned from their weight, as compared with the total weight of the products during exhaust. The speed depends on the mean speed of the engine.

Lastly, the total heat discharged from the beginning of exhaust to the admission of the fresh charge is reckoned, and the difference between it and the heat of the products remaining in the cylinder. It represents an energy transformed into— I. Energy of discharge; II. Back pressure negative work; III. Work of exhaust; and IV. Energy carried off in the water. The author concludes that, in the escaping gases and the products remaining in the cylinder, there is a certain amount of energy or work represented by their temperature. The difference between this temperature and that at the closing of the exhaust valve represents a loss of energy carried off during exhaust into the atmosphere, or to the walls. There is a perceptible increase in this heat parted with to the walls, with increase of speed in the engine.

APPENDIX D.

USEFUL CONSTANTS FOR THE CONVERSION OF MEASURES OF LENGTHS, VOLUMES, PRESSURES, HORSE-POWER, HEAT, TEMPERATURES, &c.

Measures.	English.	Metric.
Length, . .	1 inch, ...	= 0·0254 metre = 25·4 millimetres.
	1 foot = 12 inches, .	= 0·3048 metre.
	1 mile = 1760 yds. = 5820 ft., ...	= 1609·7 metres = 1·61 kilometre.
Area, . . .	1 square foot, . .	= 0·0929 square metre.
Volume, . .	1 cubic foot, . . .	= 0·0283 cub. metre = 2·83 litres.
	1 gall. = 277·274 cub. in. = 0·16 cub. ft. = 10 lbs. water at 62° F., . .	= 4·537 litres.
	1 cub. foot of water = 6·23 galls. = 62·35 lbs. at 62° F., . . .	= 28·375 litres = 0·0283 cub. metre.
Pressure, . .	1 lb. per sq. inch, . .	= 0·0703 kilo. per sq. centimetre.
	1 lb. per sq. foot, . .	= 4·883 kilogrammes per sq. metre.
	1 inch of water, . .	= 2·54 centimetres of water = 0·187 centimetres of mercury.
Weight, . .	1 lb., ...	= 0·4536 kilogramme.
Horse-power,	1 English H.P. = 33,000 ft.-lbs. per minute, .	= 1·014 metric horse-power.
Heat, . . .	1 British T. U. = 1 lb. water raised 1° F., .	= 0·252 calorie.
	1 British T.U., per lb., .	= 0·556 calorie per kilogramme.
	1 do. per cub. ft.,	= 8·9 calories per cub. metre.
	Heat equivalent of 1 English H.P. = 33,000 ft.-lbs. divided by Joule's equivalent for 1 T.U., 778 ft.-lbs. $= \frac{33,000}{778} =$ 42·4 B.T.U. per min.,	= 10·68 calories per minute.
Temperature,	To obtain degrees Centigrade deduct 32 from the degrees Fahrenheit, then multiply by 5 and divide by 9.	

USEFUL CONSTANTS FOR THE CONVERSION OF MEASURES OF LENGTHS, VOLUMES, PRESSURES, HORSE-POWER, HEAT, TEMPERATURES, &c.

Measures.	Metric.	English.
Length, . .	1 metre = 1000 millimetres, 1 kilometre = 1000 metres,	= 39·378 inches = 3·28 feet. = 3280 feet = 0·621 mile.
Area, . . .	1 square metre, . .	= 10·764 square feet.
Volume, . .	1 cub. metre = 1000 litres = 1000 kilogs. of water, 1 litre, ...	= 35·315 cub. feet = 220 galls. = 0·0353 cub. foot = 0·22 gall. = 61 cub. inches.
Pressure, . .	1 atmosphere = 1 kilogrm. per sq. centimetre, . 1 kilogramme per sq. metre, 1 centimetre of mercury,	= 14·22 lbs. per sq. inch = 2050 lbs. per sq. foot. = 0·205 lb. per sq. foot. = 5·35 inches of water = 0·193 lb. per sq. inch.
Heat, . . .	1 calorie = 1 kilogramme water raised 1° C., . 1 calorie = 427 kilogramme metres, .	= 3·986 British thermal units.
	1 calorie per kilogrm., . 1 calorie per cub. metre,	= 1·8 do. do. per lb. = 0·112 do. do. per cub ft.
	Heat equivalent of 1 met. H.P. $= \frac{75 \times 60}{427} = 10{\cdot}5$ calories per minute, .	= 41·8 Thermal units per minute.
Horse-power,	1 metric H.P. = 75 kilogramme metres per second, . . .	= 0·986 English horse-power.
Weight, . .	1 kilogramme = 1 litre of water at 4° C., .	= 2·204 lbs.
Temperature,	To obtain degrees Fahrenheit from degrees Centigrade, multiply by 1·8 and add 32.	

APPENDIX E.

NOTES FOR BLANK SHEETS FOR TESTS ON GAS OR OIL ENGINES.

It is important in reporting the results of such tests that they should be given in the same order and sequence, so that comparisons may readily be made. In such reports all facts and data relating to the engine tested should come first, and Sheet 1 be filled in. The results of the tests only should be entered on Sheet 2. Any conclusions or other information may be added. The data should always be filled in as far as possible, and in the order indicated.

It is important that the heating value of the gas or oil should be given. A simple statement of so many cubic feet of gas or lbs. of oil used per B.H.P. per hour is misleading and useless.

When the heating value is known, the thermal efficiency per B.H.P. can be calculated, and this is the best figure of merit for comparing gas and oil engine results. It is now usually adopted in Germany, France, England, and other countries.

When the thermal efficiency is known, the results of any gas or oil engine can be compared with others or with any steam engine, and these three classes of heat motors can thus be compared on a sound basis. If the thermal units are converted into their money value in the particular locality of the test, the three heat motors can be compared for cost per B.H.P. per hour. Any remarks by the chief experimenter as to the running of the engine, smell, noise, heated bearings, &c., should be added on Sheet 2. The best guarantee as between buyers and sellers of gas and oil engines is the heat efficiency per B.H.P., and the mechanical efficiency.

Heat Efficiency.—So much heat is given to a motor in the shape of gas or oil, and so much heat is obtained on the brake (Joule's heat equivalent for power). The heat efficiency per B.H.P. is the ratio per cent. of the latter to the former.

BLANK SHEETS FOR A GAS OR OIL ENGINE TEST, ENGINE RATED AT B.H.P.

SHEET No. 1.—*Facts and Data only on this Sheet.*

Line No.	Particulars Required.	Replies.
1	Date of test and name of town, &c., . . .	19 .
2	Test No., ...	No.
3	Name of chief experimenter, ...	
4	Name of motor, maker, and type, ...	
5	Kind of work on during test, and whether driven direct or otherwise, ...	
6	Object of test, ...	
7	Were all the conditions kept constant? . . .	
8	Principle of governing? Cutting out explosions or throttling charge or otherwise, ...	
9	Cylinder, horizontal or vertical. No. of cranks, .	
10	Diameter of cylinder, one or more, ...	inches.
11	Length of stroke, ...	inches.
12	Single or double-acting engine, ...	
13	Four-cycle or otherwise, ...	
14	Clearance volume, if known, ...	cubic feet.
15	Water for cooling cylinder jacket. To barrel and bottom cover or otherwise. How was quantity measured?	
16	Type and No. of valves and metal used for them, .	
17	Type and No. of piston rings and metal used, . .	
18	Add tracing of indicator diagram nearest to mean and scale, ...	
19	Name of indicator used in the test, ...	
20	Type of brake used, rope, or other, ...	
21	No. and diameter of flywheels, ...	
22	Ignition, electric, tube, or other kind, ...	
23	Scavenger air stroke or not, ...	
24	Heating value of gas or oil. How determined, and by whom?	
25	Engine without any load on. Was engine indicated thus? If so, add copy of diagram and scale, .	
26	How was gas or oil measured?	
27	Were the different tests made at different loads, full and half?	
28	Were the governing qualities of the engine tested for sudden variations of load? If so, add results,	
29	How was temperature of exhaust gases taken? .	
30	Heat balance in percentage, add if calculated, .	
31	Duration of motor stroke in seconds at nominal speed, ...	
32	Cost of gas or oil on the spot, ...	
33	Add any additional facts, ...	

Signed and Dated by Chief Experimenter.

Blank Sheets for a Gas or Oil Engine Test—Results of Experiment.
Sheet No. 2.—*Results only on this Sheet.**

Line No.	Particulars.	Headings.	Results.
1	Date of test, 19 —Barometer,	Inches.	
2	Test No., ...	No.	
3	Duration of test, ...	Hours.	
4	Name of gas or oil used in test, and specific gravity of oil, ...	Name.	
5	Condition of test, full or half power, . .	Full power or otherwise.	
6	Mean revolutions from counter on crank shaft,	Revs. per min.	
7	Piston speed in feet per minute, . . .	Ft. per min.	
8	No. of explosions per minute by counter, . .	Expl. per min.	
9	Maximum pressure (absolute) from the mean diagram, ...	Lbs. per sq. in.	
10	Calculated temperature of maximum pressure, .	F. degrees.	
11	Exhaust pressure (absolute) from the mean diagram, ...	Lbs. per sq. in.	
12	Calculated temperature of exhaust pressure, .	F. degrees.	
13	Range of temperature in cylinder during the explosion stroke. Line 10 minus Line 12, .	F. degrees.	
14	Compression pressure from mean diagram, .	Lbs. per sq. in.	
15	Compression temperature due to compression pressure, ...	F. degrees.	
16	Indicated H.P. from diagrams. Mean of diagrams, ...	I.H.P.	
17	Brake H.P., ...	B.H.P.	
18	Mechanical efficiency. $\frac{\text{Line 17}}{\text{Line 16}}$, . . .	Per cent.	
19	Gas or oil used per hour, including lamp or burner. If gas, add temperature and pressure, ...	Cub. ft. gas, or lbs. oil.	
20	Gas or oil used per I.H.P. per hour, including lamp or burner, ...	Cub. ft. gas, or lbs. oil.	
21	Gas or oil used per B.H.P. per hour, including lamp or burner, ...	Cub. ft. gas, or lbs. oil.	
22	Heating value of gas or oil used in the test at a certain temperature and pressure. T.U. per cubic foot gas or T.U. per lb. oil, ...	T.U.	
23	T.U. per I.H.P. per minute in gas or oil used, .	T.U.	
24	T.U. per B.H.P. per minute in gas or oil used,	T.U.	
25	Heat efficiency of engine per B.H.P. $\frac{42\frac{1}{4}\ \text{T.U.}}{\text{Line 24}}$,	Per cent.	
26	Cooling Jacket. Quantity used per hour, .	Lbs. water.	
27	Cooling Jacket. Temperature out F.; temperature in F. Difference or rise, mean of observations, . . .	F. degrees.	
28	Temperature of gas as used (mean), . . .	F. degrees.	
29	Temperature of air used (mean), . . .	F. degrees.	
30	Pressure of gas used in inches of water, . .	Inches.	
31	Temperature of exhaust gases, if taken, . .	F. degrees.	
32	Quantity of lubricating oil used per hour, .	Lbs.	
33	Cost of gas or oil per hour per B.H.P. at place of test, ...	Pence.	
34	If driving dynamo, give Electric H.P., . .	E.H.P.	
35	Power to drive engine empty at same speed, .	I.H.P.	
36	Notes on noise, good running, hot bearings, &c.,		

Signed and Dated by Chief Experimenter.

* In the best gas engine tests it is now (1905) usual to add the chemical analysis of the exhaust gases, from which the more or less complete combustion in the cylinder can be deduced.

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Note.—See also List of Proceedings, Periodicals, and Reports in Trials of Gas, Oil, and Air Engines.

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